2008

Calibrating plug-flow bioreactors as a tool for the assessment of dissolved organic matter biolability in lotic systems

Christopher T. Mason
Lehigh University

Mason, Christopher T.

Calibrating Plug-Flow Bioreactors as a Tool for the Assessment of Dissolved Organic Matter Biolability...

May 2008

Calibrating Plug-Flow Bioreactors as a Tool for the Assessment of Dissolved Organic Matter Biolability in Lotic Systems

By: Christopher T. Mason

Master's Thesis

Presented to the Graduate and Research Committee

Of Lehigh University

In Candidacy for the Degree of

Master's of Science

In Earth and Environmental Sciences

Lehigh University

(4/23/2008)

Approved and recommended for acceptance as a thesis in partial fulfillment of the requirements for the degree of Master of Science

4/23/2008
(Date)

Professor Donald Morris (Thesis Advisor)

Professor Bruce Hargreaves (Co-Advisor)

Professor Steve Peters (Co-Advisor)

Professor Frank Pazzaglia (EES Chair)

Acknowledgments: I would like to thank my advisor, Don Morris, for the opportunity to work on this project. Completion of this study would not have been possible without his intellectual and financial support and the guidance of Steve Peters and Bruce Hargreaves. Jason Porter was instrumental in learning numerous laboratory techniques as well as construction and maintenance of the bioreactors. Palmer Grant Funding was also supplied by the EES department and helped fund this project. Finally, I would like to thank the rest of the Earth and Environmental Sciences department at Lehigh University for allowing me this opportunity and making my graduate school experience enjoyable as well as educational.

Table of Contents

List of Tables

List of Figures

Abstract: Dissolved organic carbon (DOC) biolability and bacterial growth efficiency (BGE) are major controls on energy supply to aquatic food chains. DOC forms the base of the aquatic food chain and is processed by heterotrophic microbes, which allow the energy to be passed to higher trophic levels. Two major categories of DOC are allochthonous and autochthonous. Autochthonous DOC is produced within the aquatic environment and tends to have high biolability while natural allochthonous DOC is transported to the stream from terrestrial sources and tends to have lower biolability. Four DOC sources were used for this study. Three natural river samples, collected along the Lehigh and Delaware Rivers in Pennsylvania, were used to obtain DOC of varying composition and quantity. An algal culture was used to provide a highly autochthonous DOC source. It was expected that headwater samples would contain highly allochthonous DOC while downstream samples would become more autochthonous in nature. Bioreactors and batch cultures were used simultaneously to measure DOC biolability for each site. While a distinct trend was lacking, DOC biolability tended to be highest downstream and ranged from 8.2% at the Headwater site to 16.3% at the downstream site when measured in bioreactors and 6.0% at Headwaters to 11.0% at Midstream when measured in batch cultures. While on a different scale, biolability followed the same trend, of increasing biolability downstream, in both plug-flow bioreactors and batch cultures. BGE, measured using batch cultures, also lacked a distinct trend, but tended to be the highest in the headwaters. During the initial phase of incubation, BGE ranged from 55.8% for the Headwater site to 20.9% for the Midstream site. BGE also tended to decrease over the 21 day incubation period suggesting that high energy DOC was preferentially consumed at the outset. Comparisons between

bioreactors and batch cultures show that it is possible to predict BGE from bioreactor measurements, and simultaneous measurements provide a method for converting bioreactor biolability to batch culture biolability and vice versa. This will allow for quicker and less laborious estimates of BGE and eliminate "container effect" associated with the batch culture technique.

Introduction: Determining the functioning of aquatic ecosystems depends on an understanding of numerous intricate relationships such as the interaction between various trophic levels of a freshwater food web. One important link in this system is the assimilation of dissolved organic matter (DOM) by heterotrophic bacteria, which provides a pathway for energy transfer from DOM to higher trophic levels. Bacteria consume DOM which makes the energy contained within it available to ciliates and heterotrophic flagellates. From here, the energy can then be passed to higher trophic levels such as macroinvertebrates and fish. The efficiency at which bacteria assimilate DOM, and the fate of DOM (as energy recycled to the food web or energy lost as CO_2 via respiration), plays a critical role in understanding the functioning of aquatic ecosystems.

Dissolved organic carbon plays a vital role in stream ecosystems. It influences metal cycling (McKnight and Bencala 1990), and pH (Oliver 1983), and it provides organic matter to aquatic food webs (Meyer 1994). It also plays a major role in UV attenuation, which protects aquatic organisms from the damaging effects of UV light (Schindler and Curtis 1997). Some have even suggested that it labels streams with a unique odor, which allows salmon to locate their natal streams (Scholz 1976). In addition, Meyer et. al (1998) have calculated that DOC accounts for 3-95% of organic matter inputs to streams and 13-82% of total organic matter exports from streams, which implies that, although highly variable, carbon supplies in certain ecosystems are dominated by DOC.

The sources of DOC are as diverse as its effects on aquatic ecosystems. Two broad categories of DOC are autochthonous and allochthonous. Autochthonous DOC is produced within the aquatic environment. The autochthonous DOC in streams comes

from microbial exudates or internal recycling through processes including death and decomposition (Kaplan and Bott 1982). Autochthonous material tends to have low molecular weight, is light in color (has low DOC-specific absorbance), and has a high proportion of proteins, peptides, carbohydrates, fats, waxes, resins and amino acids.

Allochthonous DOC is produced through the death and decay of terrestrial biomass, often under anaerobic conditions. Terrestrial primary producers absorb CO_2 through photosynthesis and temporarily store carbon in their structures until consumed by heterotrophic organisms or decomposing to DOC. The major source of allochthonous DOC to streams is leaching of humic material in soils. This supply of DOC has been shown to depend on soil processes, land use and vegetation types as well as watershed slope. Carbon can also be released directly to aquatic ecosystems as leachates from throughfall or terrestrial biomass stored in the stream. Terrestrial biomass is often stored in streams as particulate organic material, which can release allochthonous carbon through microbial and chemical pathways (Meyer 1990, 1994). This process can be expedited by "sloppy feeding" of aquatic macroinvertebrates, which consume particulate organic material (Meyer and O'Hop 1983). Carbon can also be processed by terrestrial organisms and then transported to an aquatic ecosystem through surface flow (Kaplan and Newbold 1993). Allochthonous DOC tends to have higher molecular weight, consists of tannins and humic and fulvic acids, and is dark in color (high DOC-specific absorbance). Humic substances in particular are known to dominate the DOM pool in natural stream water (Wallis and Ladd 1983). As a result, energy contributed through humic materials likely plays an important role in ecosystem metabolism (Wetzel 1992).

The composition of DOC in a river is controlled by multiple environmental factors including those explained above as well as weather and geologic conditions. DOC quality may also be correlated with location along the river course if these processes vary along the river. The River Continuum Concept explains how physical processes (geology, climate) outside a river interact with riparian vegetation, which then controls the physical and biological processes within the river (Vannote 1980). The concept breaks rivers into sections based on location in the watershed. Headwater streams are dominated by shredder macroinvertebrate communities that consume coarse particulate matter from terrestrial inputs. Mid-size streams are dominated by grazers that feed on algae, which flourish as a result of increased sunlight. Finally, large rivers are dominated by macroinvertebrate collector communities that feed on particulate organic matter. All of these processes influence DOC production and consumption and likely play a roll in determining the chemical composition and biolability of DOC within specific sections of a river system.

DOC biolablity, the percentage of the DOC pool which is biologically available to microbial organisms, has been measured in a variety of aquatic ecosystems. Traditionally, these measurements have been made using batch cultures. A definitive test of biolability is lacking, but previous studies have used incubation periods of 5-20 days (Søndergaard and Worm 2000). Biolabile DOC (BDOC) is then defined as the amount of DOC consumed during this period. More recently, bioreactors consisting of glass columns filled with inert glass beads, originally developed by Lucena et al. (1990) and Frias et al. (1992), have been used to measure BDOC. Kaplan and Newbold (1995)

introduced a more refined method with their plug-flow bioreactors, which define BDOC as the amount of DOC consumed during one pass through the reactor.

Globally, BDOC accounts for about 14% of the total DOC pool in lakes (Søndergaard and Middleboe 1995). BDOC measured in White Clay Creek, Pennsylvania using plug-flow bioreactors ranged from 16.5-34.4% and averaged 25% of total DOC (Volk et al. 1997). Kim et al. (2006) found that BDOC accounted for 22% of total DOC in a tropical stream and 42% of total DOC in a temperate stream. Concentrations of BDOC in stream water are likely to vary along the river course as well as within specific sections depending on environmental, physical, and geologic characteristics. As a result, additional measurements of BDOC are required to better understand these systems. If BDOC is low, ecosystem productivity may be reduced. Additionally, if autochthonous BDOC is low the ecosystem may depend heavily on allochthonous material. The inverse would likely be true as well.

Bacterial growth efficiency (BGE), the amount of new bacterial biomass produced per unit of organic substrate assimilated (Del Giorgio and Cole 1998), has also been measured in a variety of ecosystems. However, rates are highly variable between and within ecosystems and questions about what controls BGE in specific ecosystems still remain. Del Giorgio and Cole (1998) provide a summary of *in situ* BGE measurements at a variety of sites. Large rivers including the Muese and Ogechee tend to have BGE values of around 30%. However, the Amazon River ranged from 3-46% BGE (Del Giorgio and Cole 1998) showing that ecotones can exist within a specific ecosystem, and BGE is highly variable throughout a river system. This range of values is also

supported by Kroer (1993) who measured BGE of 32% in the Perdido River and 36% in Eleven Mile Creek.

Efficiency measurements have also been conducted on specific types of DOC. Del Giorgio and Cole (1998) found that autochthonous organic carbon from phytoplankton resulted in BGE values of 31-81 % while allochthonous organic carbon from vascular plants provided BGE values of 9-92%. These broad ranges provide little assistance in predicting BGE for a specific ecosystem. Molecular weight has also been used to define fractions of DOC. Traditionally low molecular weight (LMW) compounds were believed to be more bioreactive (Meyer et al. 1987). However, more recent studies have shown that while LMW compounds result in higher BGE (16-66%) than high molecular weight compounds (HMW) (8-39%), bacterial growth and respiration rates are higher in HMW incubations (Amon and Benner 1996), which raises more questions about what is truly controlling BGE. An ecosystem with high BGE will transfer energy efficiently and likely be highly productive. However, the productivity of ecosystems with low BGE will be limited and possibly lead to an altered food web with decreased trophic richness.

Previous studies have resulted in numerous hypotheses regarding what controls BGE in natural environments. Del Giorgio and Cole (1998) suggest that BGE varies systematically with bacterial production and trophic richness, and that BGE should increase with nutrient supply. Kroer (1993) also contends that nutrients play a role by predicting that elevated BGE values in a small creek were due to exogenous sources of nitrogen (ammonium and nitrate). Additional measurements of BGE from a variety of sources will provide better understanding of what controls DOC cycling in these systems.

Project Goals and Hypothesis: The principal goal of this project was to analyze the biolability and bacterial growth efficiency of various sources of DOC. It also examined how DOC composition and quantity, BGE and biolability vary along the river gradient. It is expected that the DOC concentrations and quality will vary depending on sampling location. According to the River Continuum Concept, the headwater samples are expected to have highly allochthonous DOC while the lower reaches of the river should provide samples with more autochthonous DOC. Finally, the DOC from an algal culture should be highly autochthonous. The results of this study will help to improve knowledge of DOC dynamics within lotic systems. It will also provide insight into how DOC varies along the river course.

A secondary goal of this project, which is discussed in Section Two, was to calibrate plug-flow bioreactors with traditional batch culture methods to develop an easy and reliable method of assessing DOM biolability to aquatic microorganisms. Batch cultures have traditionally been used to assess DOM biolability (Del Giorgio and Cole 1998), and careful application of this method has the advantage of being able to determine bacterial growth efficiency (BGE) in addition to DOM biolability. However, the use of batch cultures is problematic due to diverse metabolic responses of natural bacterial cultures from "container effect", which excludes the production of complex bacterial communities (Sondergaard and Worm 2001) and requires long incubation times (Del Giorgio and Cole 1998). Even over long incubation times, O_2 consumption and CO_2 production are often very small and difficult to assess. In contrast, plug-flow bioreactors can be used as a tool to assess DOM biolability within a few hours and provide large, more easily measured values for O_2 consumption and CO_2 production. However, unlike

batch methods, bacterial production cannot be measured in plug-flow bioreactors (Kaplan 1996). So, direct estimation of BGE is not possible. As previously mentioned, determining BGE with batch cultures is difficult and time consuming. This research attempts to calibrate bioreactors with traditional batch culture techniques and hypothesizes that these bioreactors will provide a faster and less laborious way of determining the biolability of DOM as well as an innovative method for predicting BGE.

Importance and Expectations: If it can be demonstrated that bioreactors and batch cultures provide similar results, in DOC consumption and biolability, across a wide range of DOM types, then bioreactors can serve as important experimental platforms in evaluating DOM metabolism. Bioreactors could be used to evaluate DOM biolability from a variety of natural sources (e.g. allochthonous vs. autochthonous), study the role of photobleaching on DOM biolability, or investigate the role of inorganic nutrient limitation in DOM biolability. By comparing the composition of inflow and outflow DOM it is also possible to determine the nature of the organic material used to support microbial metabolism in aquatic ecosystems.

This type of calibration between batch cultures and plug-flow bioreactors has never been attempted in a lotic ecosystem. If successful, it will provide a new tool for understanding DOM metabolism. It will also allow for faster and less laborious analysis of what influences DOC biolabilty. In addition, it will provide insight into what processes are controlling DOC biolability within the Lehigh River. This will enable better understanding of how the microbial community, and food-chain as a whole, reacts to changes along the river gradient. It will also provide background for predicting how the system will respond to changes in physical and environmental conditions due to

changes in pollution, landscape characteristics and climate. Of additional importance is the incorporation of bacterial growth efficiency measurements. These measurements are rare in the literature and often difficult to collect. The research presented here provides additional BGE measurements, which again will improve our knowledge of how ecosystems react to varying conditions.

Combined measurements of biolability and BGE will provide better understanding of how energy is transferred between trophic levels. As previously mentioned, bacteria play a major role in aquatic detrital food webs. Production in heterotrophic systems including estuaries (Findlay et al. 1992) can be highly dominated by bacteria, which can even outweigh primary production (Hall and Meyer 1998). Additionally, bacteria represent the trophic base of the food chain. As a result, the efficiency with which carbon (energy) is consumed and transferred by bacteria is extremely important. If autochthonous sources of DOC do not provide sufficient biolability or BGE, the ecosystem will be more dependent upon allochthonous DOC derived from the surround watershed. This is especially important considering that filtering blackflies and scraping mayflies can derive between 20-67% of their carbon from bacteria (Edwards and Meyer 1987, 1990), and these organisms are in turn consumed by larger organisms including fish. Inefficient consumption of DOC by bacteria could lead to a significant alteration and possible collapse of the food web.

Methods:

Sampling Sites: Three sites were selected based on their position in the watershed according to the "River Continuum Concept." These sites and their locations are listed in Table 1. Additionally, an algal culture was grown to produce DOM characteristic of a

highly autochthonous source. The algal culture was grown in an artificial pond in a greenhouse at Lehigh University. The source water was taken from an onsite natural spring and Lehigh River water collected in Bethlehem, Pennsylvania. The culture was fertilized with nitrogen (NH_4Cl) and phosphorus ($Na\text{-}PO_4$ Tribasic) to encourage algal growth.

As previously mentioned, the three natural sites were selected based on their position in the watershed, and land use was estimated using the National Land Cover Dataset Classification System (http://gisdata.usgs.net/website/MRLC/viewer.htm). This was done to obtain natural DOM of varying quantity and composition ranging from highly allochthonous in the headwaters to highly autochthonous in downstream sections. The site selected for allochthonous DOM was the Lehigh River just north of Thornhurst, Pennsylvania. This site, located in the Poconos, has land use with limited development and a high percentage of deciduous forest and woody wetlands.

The second sampling site was the Lehigh River at Bethlehem, Pennsylvania. Water was collected from the canoe access point on Sand Island just north of the interstate 378 bridge. Because of its location along the river course, this site was predicted to provide a mixture of allochthonous and autochthonous DOC. Land use upstream of this area is dominated by high and low density residential use as well as commercial, industrial, transportation uses; it also includes a small amount of deciduous forest as well as communities discharging municipal wastewater.

Finally, a site was selected along the Delaware River to obtain DOM from a higher order stream. Due to its higher stream order and increased sunlight, this site should provide more autochthonous DOC released from photosynthetic microbial

community. The Delaware River was sampled at Washington Crossing State Park two miles south of New Hope, Pennsylvania. Land use above this area is a mixture of agricultural lands, deciduous forest and a small amount of light and heavy residential uses.

Sample Collection: Samples were collected at each site using acid washed 5 gallon polycarbonate bottles. Samples were transported back to Lehigh University in the dark to eliminate the potential for photosynthesis and photo-bleaching. Samples were then filtered immediately using a peristaltic pump and 0.7 μm Whatman GF/F filters. Source water for the bioreactors was kept in the dark and allowed to reach room temperature before use to prevent thermal shocking of bioreactors.

Bioreactor Design: The plug-flow bioreactors were constructed as described by Kaplan and Newbold (1995) and shown in Figure 1. They consisted of glass liquid chromatography columns, filled with Siran® sintered glass beads. The columns had an internal diameter of 2.5 cm and were 30 cm long. Teflon column end plugs with ¼ inch 28 male UNF threads and bed supports closed the end of the columns. A peristaltic pump with 1/8" PEEK® tubing (to prevent gas diffusion) was used to pump source water to the bioreactors. The flow rate was maintained at 1 ml min^{-1}, which provided a residence time in the column of approximately 3 hours. It also provided sufficient flow to eliminate possible clogs in the system. According to Kaplan et al. (1996), a high flow rate balanced with long residence time is essential for the establishment of large microbial communities.

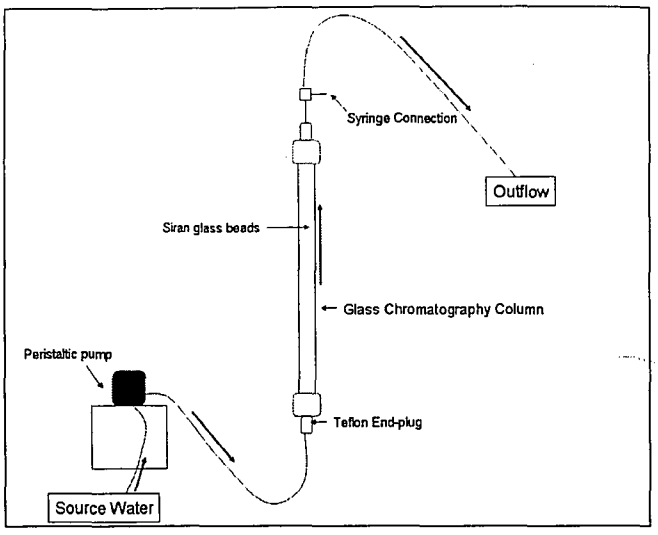

Figure 1: Bioreactor schematic.

To establish a sufficient microbial community the plug-flow bioreactors required an initial incubation period of four months as described by Riemann and Sondergaard (2003). This was necessary both to establish large microbial communities as well as to equilibrate the four columns with one another. The initialization of the bioreactors was started on December 19, 2006 and was complete by April 2006. Following the method of Sondergaard and Worm (2001), the reactors were deemed ready when DOC and DO consumption as well as CO_2 production rates were equal across all four reactors.

Bioreactors and source water containers were wrapped in foil and kept in the dark to eliminate photosynthesis. The source water was kept at room temperature in the lab (20-21° C).

Bioreactor Experimental Design: After filtration and warming to 20° C, sample water was transferred to acid washed and high-temperature cleaned glass containers to act as source water for the 4 matched bioreactors. The reactors were allowed to run for at least 12 hours (4 residence periods) to ensure that the columns were saturated with new sample

water. Sample collection consisted of an "initial" sample from the source water and a "final" sample from the outflow of the bioreactors (1 pass through the bioreactor). Comparisons of the initial and final samples were used to asses the effect of microbial processing across the bioreactors. For measurements of, dissolved oxygen and CO_2, a syringe was connected directly to the 1/8 inch PEEK tubing to avoid exposure to the atmosphere. Initial sample water was collected by gently drawing water into the syringe from the source container. For the outflow sample the positive pressure of the bioreactor pump was used to fill the syringe. Dissolved oxygen samples were then dispensed into a 60 ml acid washed and ashed glass BOD bottle with a sintered glass stopper. Care was taken to avoid oxygenation of the samples. Dissolved oxygen was then measured using the modified Winkler technique described below. Syringes for CO_2 measurements were immediately covered with Parafilm, and CO_2 was measured using the gas chromatograph method described below. A 40 ml sample was also collected into an acid washed and ashed glass beaker for pH measurements, which were conducted immediately using a portable Orion SA 250 pH meter with a Thermo Ross™ pH probe. A two point calibration was used with 7 and 10 or 7 and 4 buffers. Finally, samples for subsequent analysis of DOC concentration and spectral properties, TDN and TDP were collected and stored in 40 ml acid washed and muffled glass ARCHIV vials with Teflon caps. Initial samples for pH, DOC, TDN and TDP were collected by gently pouring source water into an acid washed and muffled glass beaker for pH and an acid washed and muffled ARCHIV vial with a Teflon cap for other analyses. Bioreactor outflow water was collected in acid washed and muffled glass beakers for final measurements of pH, DOC, TDN, and TDP. Again, samples for DOC, TDN and TDP were stored in acid washed and

muffled ARCHIV vials with Teflon caps. Sample replication was achieved by splitting the sample into 2 initial samples and duplicating all of the test and procedures using 2 separate, but identical bioreactors.

Batch Culture Set-up: Batch cultures were set up using the flow-through incubation system described by Del Giorgio (2006). The system consisted of two acid washed 4 liter glass Erlenmeyer flasks connected by Tygon® tubing. An elevated flask acted as the reservoir flask and was open to the atmosphere. The bottom flask was the incubation flask and a siphon was established between the two flasks. The flasks were filled with 0.7 μm filtered (Whatman GF/F) water from the sites along the Lehigh and Delaware Rivers. The incubation time for each sample set was 21 days. Sub-samples were collected on days 1, 7, 14 and 21; the reservoir flask refilled the incubation flask to maintain an air-tight environment. Batch cultures were maintained in the dark (to eliminate photosynthesis) and at identical temperatures.

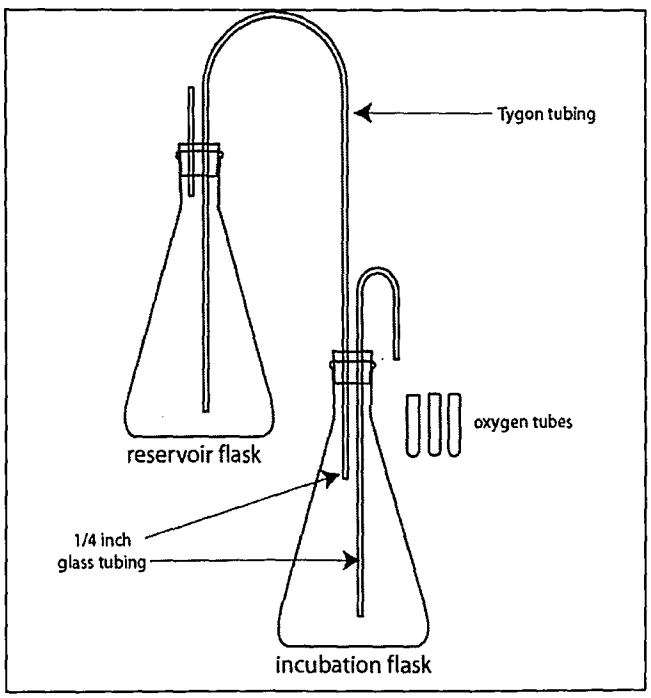

Figure 2: Batch culture schematic (Del Giorgio and Cole 1998).

Batch Culture Experimental Design: Four replicate batch cultures were run simultaneously for each sample site, and were constructed following the method described above. The batch cultures were then sampled simultaneously on incubation days 1, 7, 14, and 21. To avoid sampling water held in the tubing and not the flask a small amount of water was allowed to flow out of the batch culture prior to sample collection. A 20 ml sample was then collected in a graduated cylinder and transferred to a scintillation vial for bacterial production measurements. Water for DO and CO_2 measurements was collected by attaching a 60 ml syringe directly to the outflow of the batch culture. Again, this was done with care to avoid exposure to the atmosphere and to avoid contamination. The DO samples were then transferred to 60 ml acid washed and muffled glass BOD bottles with sintered glass stoppers. Syringes for CO_2 measurements were immediately Parafilmed and analyzed following the method described below. A 40 ml sample was collected into an acid washed and muffled beaker and immediately used for pH measurement. Finally, a 40 ml acid washed and muffled glass ARCHIV vial with a Teflon cap was used to collect a sample for subsequent analysis of DOC, TDN, and TDP. Samples were collected simultaneously from 4 batch cultures to provide sample replication.

Respiration Rate: Bacterial respiration (BR) rates were measured using identical techniques in both the batch cultures and the bioreactors. For the bioreactors this was done by measuring the loss of dissolved oxygen (DO) after flowing through the bioreactors once. In the batch cultures, it was measured from the rate of DO loss over time. Oxygen consumption was converted to CO_2 production using a respiratory quotient of 1. Dissolved oxygen was measured using a Modified Winkler Technique (Parsons

1984). Water was collected in 60 ml acid washed and muffled BOD bottles and 2.4 ml of 3M mangonous chloride solution and 2.4 ml of a 3M sodium hydroxide/iodide solution were added and mixed by inverting the bottle. This produced a precipitate, which was allowed the to settle half way down the bottle, before 2.4 ml of 10N sulfuric acid was added to re-dissolve the precipitate. Three to 5 minutes after acidification a 1 ml aliquot of iodine-containing solution was diluted to 25 ml. The extinction coefficient of iodine at 287.5 nm was then measured using a Shimadzu UC-1601 UV-Visible Spectrophotometer and a 1 cm quartz cell to determine dissolved oxygen concentration. Care was taken during sample collection and mixing to avoid aeration of the sample.

Dissolved Inorganic Carbon (DIC): DIC was measured using a gas chromatograph method. A 25 ml sample was collected in a 60 ml syringe and acidified with 1 ml of 0.1 N H_2SO_4. After acidification, 25 mls of zero grade compressed nitrogen gas was added, and the syringe was capped with Parafilm and shaken for 60 seconds. The head space from the syringe was then injected into a Shimadzu GC-8A gas chromatograph through a plastic tube containing granular Drierite. Care was taken to avoid injecting water into the GC. DIC was then measured as micromole per liter of C using a calibration curve, which consisted of 0, 100, 500, 1000 and 1500 μM standards of Na_2CO_3.

Bacterial Production: Bacterial production (BP) was measured in batch cultures using the ^{3}H-Leucine incorporation method described by Petit et al (1999). In short, 20 ml of water was collected into scintillation vials from each batch culture. An additional sample was collected and used as a killed sample. The killed sample was made up to 5% TCA by adding 1 ml of 100% TCA to a 20 ml vial. A combination of hot and cold ^{3}H-Leucine was then added to obtain a final concentration of 30 nm (5 nm hot and 25 nm cold).

After a one hour incubation period 1 ml of sample was transferred, in triplicate, to microfuge tubes containing 100% TCA to kill the bacteria and end incubation. Bacteria were then collected using centrifugation and rinsed with TCA and 70% ETOH. After rinsing, 1 ml of liquid scintillation cocktail was added to each tube and bacteria were re-suspended using a vortex. Leucine incorporation was then measured with a Wallac 1409 Liquid Scintillation Counter. Leucine incorporation was converted to BP using a factor of 3.1 kg mol leu^{-1} (del Giorgio 2006).

Bacterial Growth Efficiency: Bacterial growth efficiency (BGE) in batch cultures was defined as the amount of new bacterial growth produced per unit of organic substrate assimilated (Del Giorgio and Cole 1998). This can be expressed as:

$$BGE = (BP)/(BP+BR) \quad (1)$$

Where bacterial secondary production (BP) is defined as the amount of substrate transformed to bacterial biomass, and bacterial respiration (BR) is the amount respired to inorganic carbon (CO_2).

Dissolved Organic Carbon: Samples for DOC analysis were collected in acid washed and muffled 40 ml glass vials with Teflon caps. DOC concentration was measured using a Shimadzu TOC-V CPH Total Organic Carbon Analyzer with ASI-V auto sampler. Standards of 0, 5 and 10 ppm DOC were used to calibrate the machine. Standards and blanks were measured simultaneously with sample water, and at least one of each standard was run for every 20 samples. Raw samples were used for DOC analysis and

were not re-filtered after initial filtration of source water. External acidification was used for each sample and measurements were done following the method of Sharp (1993).

DOC Quality: Fluorescence and absorbance properties were measured to provide a qualitative indication of DOC from each sample. A Shimadzu RF-551 Fluorescence HPLC monitor and a 1 cm cell were used for fluorescence measurements. All measurements were conducted on room temperature samples and corrected by subtracting a deionized water blank. Fluorescence measurements were made using an excitation wavelength of 370 nm and emission was measured from 400-700 nm following the method of McKnight et al. (2001). An F-ratio was calculated using the ratio of blank-corrected emission intensity at two wavelengths (450:500 nm). Fluorescence measurements were also used to calculate total fluorescence and DOC-specific fluorescence. Total fluorescence was calculated as the wavelength integrated from 400-650 nm. The DOC-specific fluorescence was simply the total fluorescence divided by DOC concentration (in mgC l^{-1}) of the sample.

A Shimadzu UV-1601 UV-Visible Spectrophotometer with a 10 cm quartz cell was used for absorbance measurements on wavelengths from 200-800 nm. Absorption coefficients were calculated according to Kirk (1994). The spectral slope was calculated using the slope of the regression line of the natural log of absorption coefficient vs. wavelength (320-400 nm and 280-320 nm). The DOC specific absorbance 320nm was calculated by dividing the absorption coefficient at 320 nm by the DOC concentration (mgC l^{-1}) (Morris 1995).

DOC Biolability: DOC biolability was defined as the percentage of DOC consumed by one pass through the bioreactors (single flow through with residence time of 3 hours).

When determined for batch cultures, biolability is defined as the percentage of DOC consumed during the 21 day incubation.

(2) Biolability = (Initial [DOC]- Final [DOC]) / Initial [DOC]

Nutrient Analysis: Total dissolved nitrogen (TDN) was measured using a Shimadzu TNM-1 with a Shimadzu ASI-V auto-sampler. Sample measurements were calculated using a standard curve of 0.25-10ppm N and corrected for instrument variance using blanks and standards of 2 and 5 ppm N. Blanks and standards were measured every 20 samples.

Total dissolve phosphorus (TDP) was measured using a wet chemistry technique following oxidization with potassium persulfate (Solorzano, and Sharp 1980).

SECTION 1: Changes in DOC biolability and Bacterial Growth Efficiency along the River Course.

Results:

Water Quality: Table 1 provides a description of sampling sites as well as their locations. Table 2 provides an overview of DOC quantity and quality from the four sites. The DOC concentrations varied between 1.98 (± 0.08) and 5.29 (± 0.65) mg C l^{-1} with the highest and lowest being at the Headwater and Midstream site respectively. DOC quality also varied between sites suggesting that DOC of varying composition and origin was likely included in the survey. DOC-specific fluorescence was the only parameter which followed the expected trend by increasing upstream, thus suggesting a greater influence of allochthonous DOC (Table 2).

Nutrient data are presented in Table 3. Of the river samples, the midstream site had the highest nutrient concentrations with 1.88 ppm TDN and 36.9 ppb TDP. The highest C:N ratio (16.42) was observed at the headwater site and the lowest C:N ratio at the midstream site (1.10). The highest C:P ratio in river samples was 631 in the headwaters while the lowest was 182 at the downstream site. The algal sample was lower than any of the river samples with a C:P = 131.**Table 1; Sample Locations**: Sample names and locations for 4 water sources.

Sample ID	Site Description	Site Location
Algal	Algal culture grown in green house at Lehigh University	
Downstream	Delaware River at Washington Crossing State Park, PA	40° 20' 04.47" N 74° 56' 14.29" W
Midstream	Lehigh River at Bethlehem, PA (Sand Island)	40° 36' 54.23" N 75° 23' 10.31" W
Headwater	Lehigh River at Thornhurst, PA	41° 11' 03.44" N 75° 34' 35.33" W

Table 2; DOC quantity and quality: Average DOC concentrations and DOC quality measures of sample water with 95% CI.

Sample	DOC (mg l^{-1})	DOC Spec. Abs. (mg l l^{-1} m^{-1})	Spectral Slope (nm l^{-1})	F-Ratio (450:500 nm)	DOC Spec. Fsum (mg l l^{-1} m^{-1})	n
Algal	3.81 ± 0.13	1.14 ± 0.02	0.0198 ± 0.0004	2.29 ± 0.05	4902 ± 118	14
Downstream	2.90 ± 0.18	2.86 ± 0.07	0.0163 ± 0.0001	1.49 ± 0.02	5930 ± 121	20
Midstream	1.98 ± 0.08	2.75 ± 0. 07	0.0167 ± 0.0003	1.59 ± 0.02	8834 ± 563	22
Headwater	5.29 ± 0.65	3.90 ± 0.15	0.0170 ± 0.00008	1.38 ± 0.01	8255 ± 106	24

Table 3; Nutrients: Average nutrient concentrations and ratios with 95% CI.

Sample	TDN (ppm)	C:N	TDP (ppb)	C:P
Algal	1.90 ± 0.09	2.03 ± 0.16	49.2 ± 31.9	131 ± 58.28
Downstream	0.84 ± 0.02	3.46 ± 0.28	19.5 ± 7.0	182 ± 41.87
Midstream	1.88 ± 0.20	1.10 ± 0.14	36.9 ± 27.6	207 ± 209.34
Headwater	0.33 ± 0.03	16.42 ± 2.44	10.1 ± 3.4	631 ± 149.37

Table 4; DOC Biolability: DOC consumption and biolability measured in plug-flow bioreactors and batch cultures with 95% confidence intervals (P-values calculated using ANOVA test to show significance of change from initial to final DOC concentration).

Sample	Initial DOC ($mg\ l^{-1}$)	Final DOC ($mg\ l^{-1}$)	Difference ($mg\ l^{-1}$)	Biolabile DOC (%)	P	n
Algal reactor	3.88	2.44	-1.44 ± 0.11	36.96 ± 3.09	<0.01	10
Downstream reactor	2.82	2.36	-0.46 ± 0.07	16.25 ± 2.12	<0.01	16
Midstream reactor	1.93	1.66	-0.32 ± 0.07	13.66 ± 3.52	<0.01	18
Headwater reactor	5.28	4.84	-0.45 ± 0.10	8.21 ± 1.15	0.41	20
Algal batch	3.63	2.94	-0.69 ± 0.06	19.07 ± 1.51	<0.01	4
Downstream batch	3.21	2.94	-0.26 ± 0.09	8.24 ± 2.96	<0.01	4
Midstream batch	2.25	2.00	-0.25 ± 0.16	11.01 ± 6.77	0.02	3
Headwater batch	5.30	4.98	0.32	6.02		1

Table 5; DIC Production: DIC production in plug-flow bioreactors and batch cultures with 95% confidence intervals (P-values calculated using ANOVA test to show significance of change from initial to final DIC concentration).

Sample	Initial DIC ($\mu M\ C\ l^{-1}$)	Final DIC ($\mu M\ C\ l^{-1}$)	DIC Production ($\mu M\ C\ l^{-1}$)	P	n
Algal reactor	61.68	72.19	10.50 ± 2.57	<0.01	10
Downstream reactor	66.32	71.34	5.02 ± 0.65	<0.01	16
Midstream reactor	94.15	98.96	4.81 ± 1.27	0.07	18
Headwater reactor	17.96	22.27	4.31 ± 0.34	<0.01	20
Algal batch	64.39	74.07	9.68 ± 4.59	<0.01	4
Downstream batch	73.16	78.05	4.89 ± 1.49	<0.01	4
Midstream batch	96.36	98.72	2.36		1
Headwater batch	17.89	23.60	5.70 ± 0.39	<0.01	4

DOC Consumption: Biolability in the bioreactors ranged from 8.21% in the headwaters to 36.96% in the algal culture (Table 4). Batch culture biolability values were generally lower and ranged from 6.02% in the headwaters to 19.07% in the algal culture. Both methods showed identical trends in biolability with decreased biolability towards the headwaters. Changes in biolability are also shown in Figure 3 for the bioreactors and Figure 4 for the batch cultures. The 95% confidence intervals show that differences in biolability were not statistically significant between the midstream and downstream site (Figure 3). This was also the case when comparing the midstream site and the headwater site. Significant differences in biolability only occur when comparing the Algal and Downstream site or the Algal and Headwater site (Figure 4).

Production of DIC, as a result of DOC respiration, through the batch cultures and bioreactors is shown in Table 5. Initial DIC ranged from 17.89 μM C l^{-1} at the Headwater site to 96.36 μM C l^{-1} at the Midstream site. DIC production through one incubation period in the batch cultures ranged from 2.36 μM C l^{-1} at the Midstream site to 5.70 ($\pm$ 0.39) μM C l^{-1} at the Headwater site. DIC production through one incubation period in the bioreactors ranged from 4.31($\pm$ 0.34) μM C l^{-1} at the Headwater site to 5.02 ($\pm$ 0.65) μM C l^{-1} at the Downstream site.

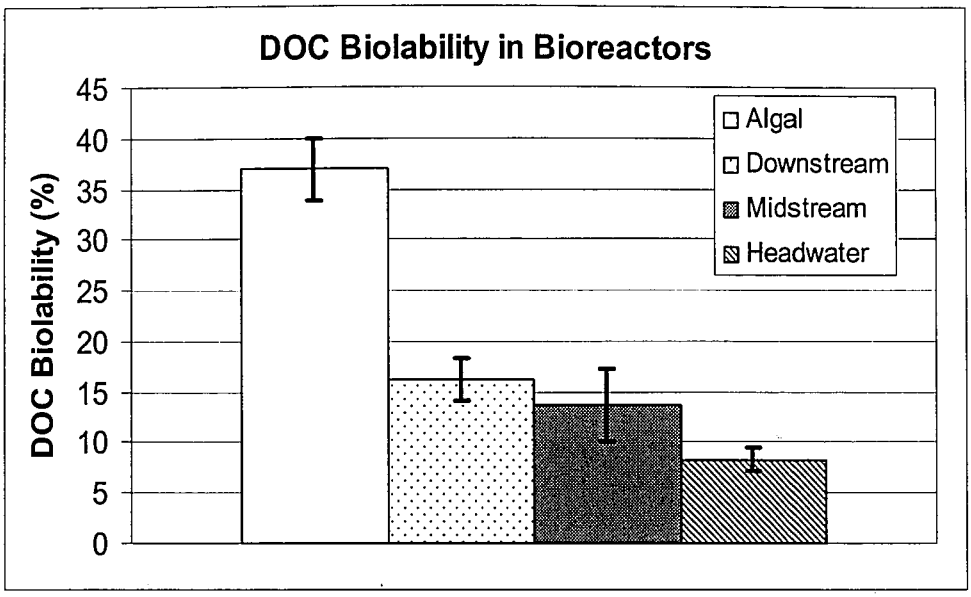

Figure 3: Average biolability measured in bioreactors with 95% confidence intervals (Algal n= 10, Downstream n= 16, Midstream n= 18, Headwater n= 20).

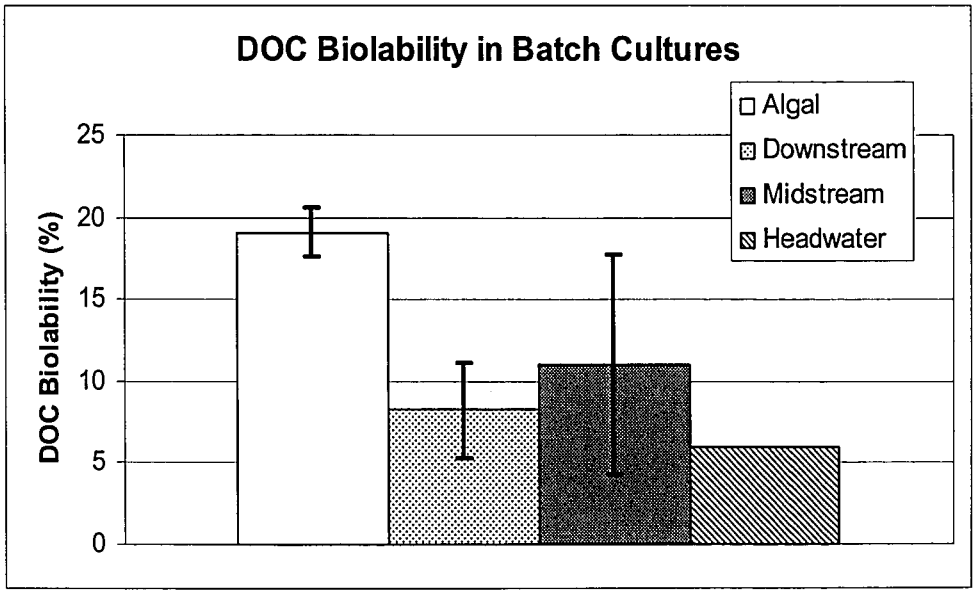

Figure 4: Average biolability measured in batch cultures with 95% confidence intervals (Algal n= 4, Downstream n= 4, Midstream n= 3, Headwater n= 1).

Figures 5 and 6 show the relationship between initial DOC concentration and DOC biolability in the bioreactors. No significant relationship exists when using all bioreactor measurements (Figure 5). A significant relationship exists when using only river samples (Figure 6), but minimal variance is explained by this relationship (n= 54, P= 0.03, r^2= 0.09). Figure 7 shows that no significant relationship (n=16, P=0.68) exists

between DOC biolability and initial DOC concentration when using batch culture techniques.

The influence of nutrients on biolability was also examined. No significant relationship existed between TDN or C:N and biolability in the batch cultures. In the bioreactors however, a significant positive relationship (P=0.0001, n=64, r^2=0.205) was observed between TDN and biolability as shown (Figure 8). There was significant inverse correlation (P= 0.0004, n= 64, r^2= 0.1837) between C:N and biolability, which is shown in Figure 9. This suggests that nitrogen availability is playing a role in controlling biolability but does not explain a large fraction of its variability in the data set. TDP and C:P were not significantly correlated with biolability in the bioreactors or the batch cultures. N:P ratios however, showed a significant relationship (P-value <0.01, n=62, r^2= 0.2465) with biolability (Figure 10).

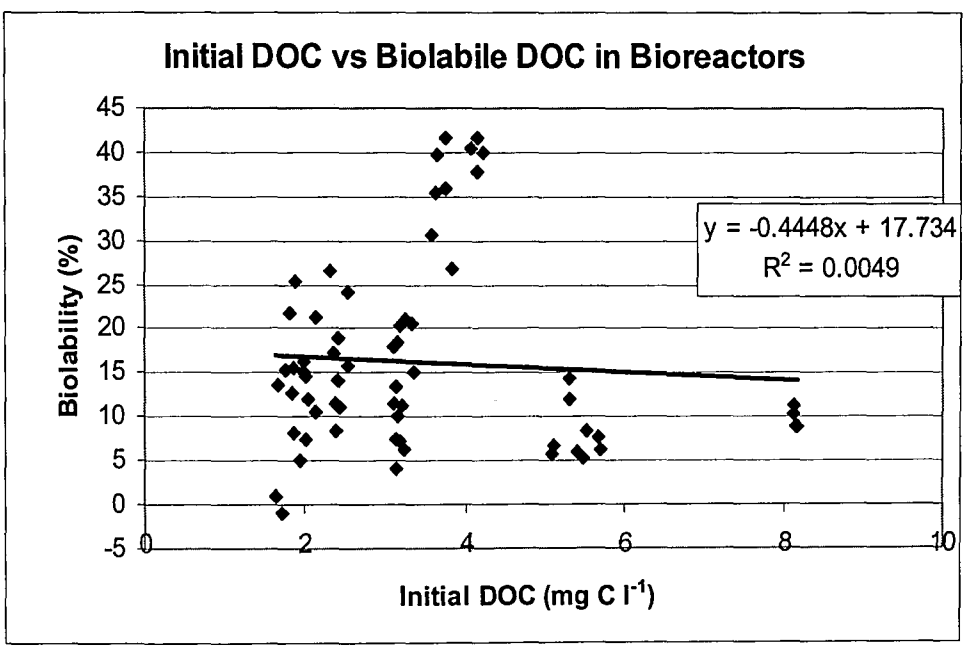

Figure 5: DOC biolability was not significantly correlated with initial DOC concentration (P= 0.58, n= 64).

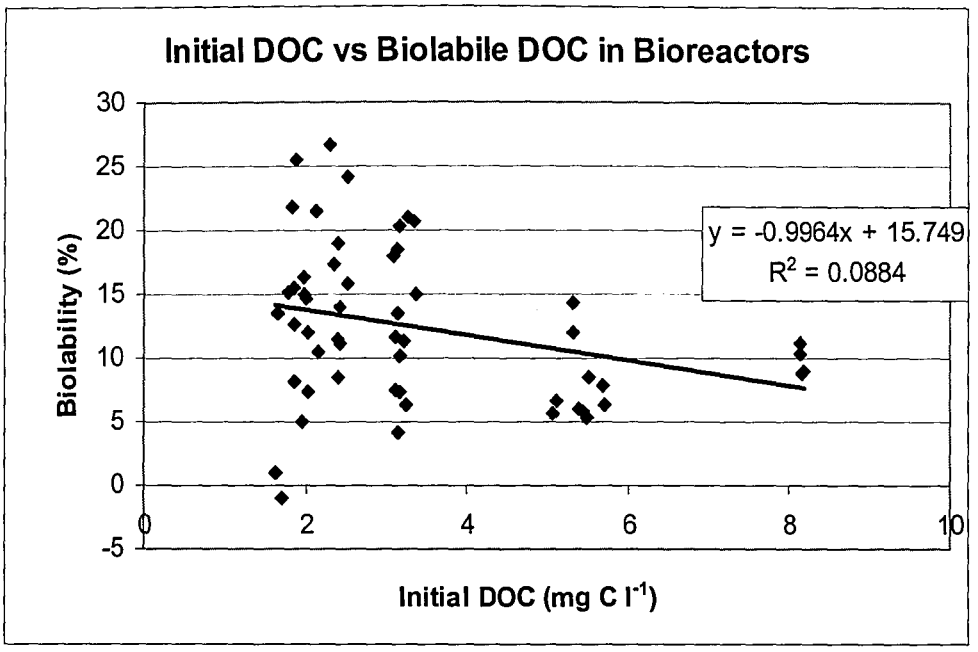

Figure 6: DOC biolability in river samples was negatively correlated with initial DOC concentration. (P= 0.029, n= 54).

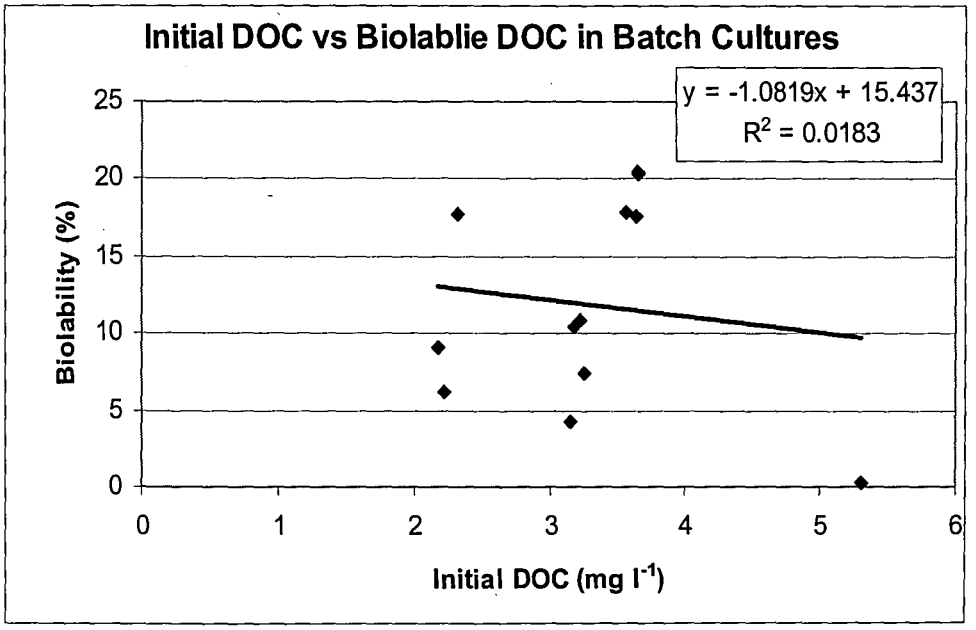

Figure 7: DOC biolability in the batch cultures was not significantly related to initial DOC concentration (n= 12, P= 0.68).

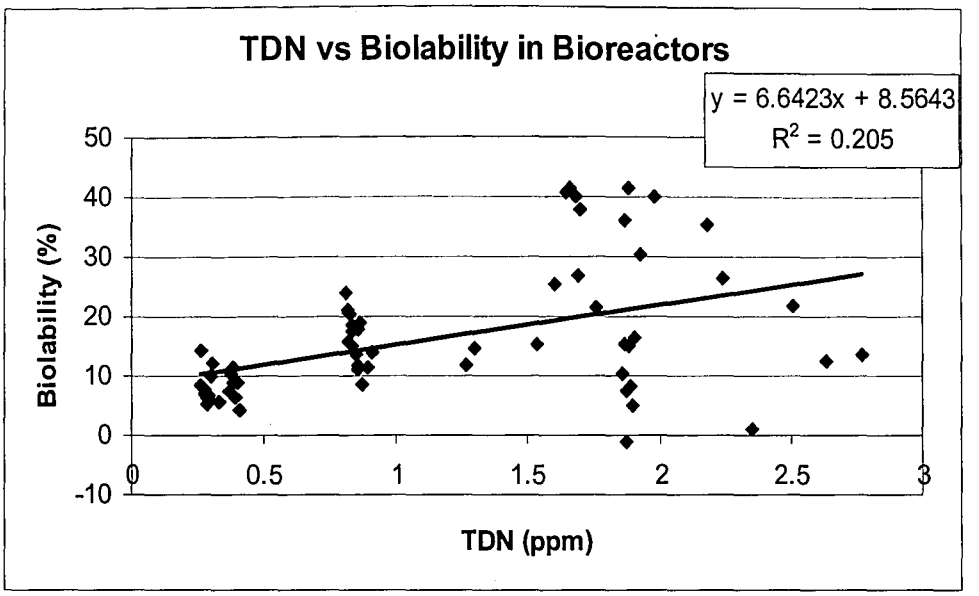

Figure 8: A positive relationship exists between TDN and DOC biolability (P= 0.0001, n= 64).

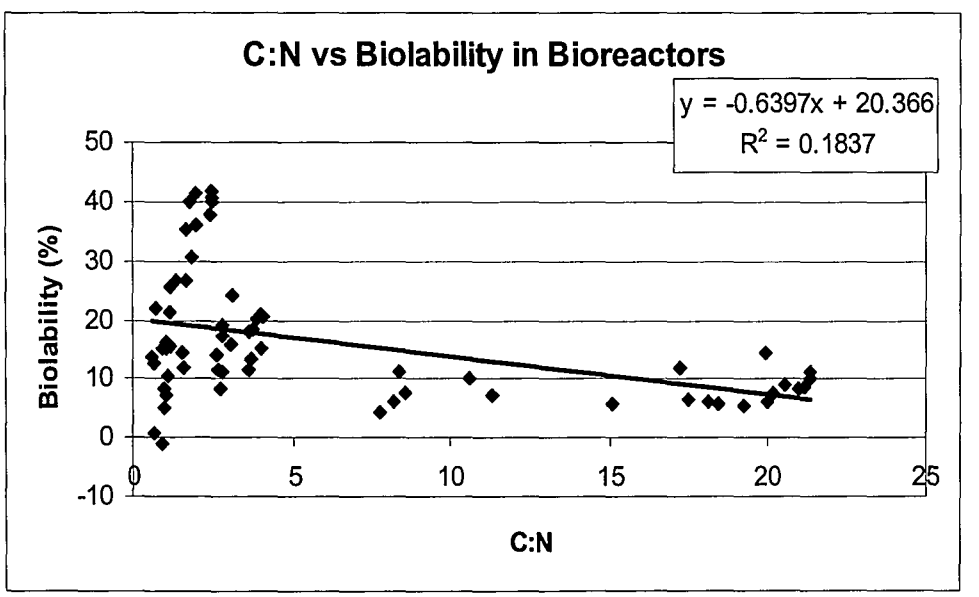

Figure 9: A negative relationship exists between C:N and DOC biolability (P= 0.0004, n=64).

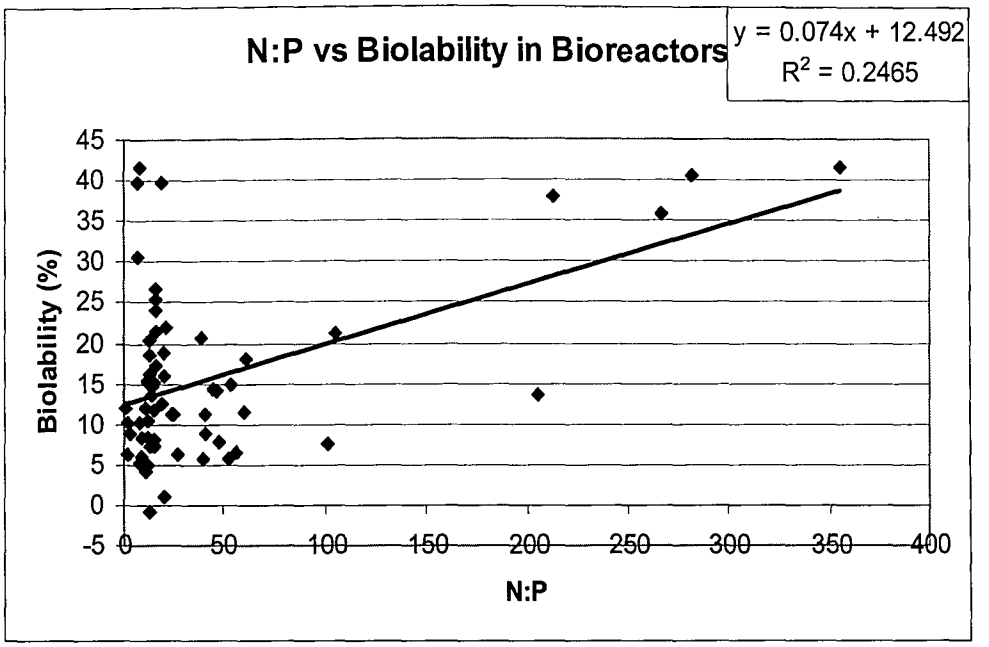

Figure 10: DOC biolability positively correlated with N:P in bioreactor samples (P-value <0.01, n=62).

DOC Composition: DOC quality was assessed at the beginning and end of each incubation period. The results of these spectrofluorometric measures are shown in Tables 6-9. Of these indices, DOC-specific fluorescence (Table 7) and spectral slope (Table 9) showed the most significant change in DOC quality before and after incubation. F-ratio only varied significantly for 2 of 8 samples (Table 6) while DOC specific absorbance only showed significant change in 4 of 8 samples (Table 8).

Table 6; F-Ratio: Changes in F-ratio after one incubation period with 95% confidence intervals.

Sample	Initial F-Ratio	Final F-Ratio	Difference	P	n
AL reactor	2.32	2.15	-0.17 ± 0.05	<0.01	10
DS reactor	1.50	1.50	-0.00 ± 0.02	0.86	16
MS reactor	1.60	1.56	-0.04 ± 0.01	0.01	18
HW reactor	1.38	1.40	+0.02 ± 0.01	0.15	20
AL batch	2.23	2.24	+0.01 ±0.02	0.41	4
DS batch	1.47	1.46	-0.01 ± 0.03	0.30	4
MS batch	1.54	1.56	+0.02 ± 0.03	0.28	4
HW batch	1.35	1.35	+0.01 ± 0.01	0.38	4

Table 7; DOC Specific Fsum: Change in Specific Fsum after one incubation period with 95% confidence interval. The increase in Fsum suggests a change to more allochthonous DOC through consumption of autochthonous DOC.

Sample	Initial DOC Spec. Fsum ($mg\ l^{-1}\ m^{-1}$)	Final DOC Spec. Fsum ($mg\ l^{-1}\ m^{-1}$)	Difference	P	n
AL reactor	4870	6504	+1634 ± 472	<0.01	10
DS reactor	5950	6468	+517 ± 185	<0.01	16
MS reactor	9025	9321	+296 ± 558	0.49	18
HW reactor	8213	8663	+449 ±110	<0.01	20
AL batch	4981	6092	+1110 ± 153	<0.01	4
DS batch	5850	6773	+923 ± 326	<0.01	4
MS batch	7975	9014	+1039 ± 406	<0.01	4
HW batch	8464	8593	+128 ± 693	0.73	4

Table 8; DOC Specific Absorbance: Change in DOC specific absorbance (320 nm) after one incubation period with 95% confidence interval.

Sample	Initial DOC Spec. Abs. (mg $l^{-1}\ m^{-1}$)	Final DOC Spec. Abs. (mg $l^{-1}\ m^{-1}$)	Difference	P	n
AL reactor	1.14	1.62	+0.48 ± 0.04	<0.001	10
DS reactor	2.82	2.88	+0.06 ± 0.04	0.29	16
MS reactor	2.75	2.89	+0.14 ± 0.09	0.012	18
HW reactor	3.82	3.94	+0.11 ± 0.07	0.32	20
AL batch	1.16	1.37	+0.21	<0.001	4
DS batch	3.02	3.03	+0.005	0.92	4
MS batch	2.74	2.82	+0.074	0.33	4
HW batch	4.31	4.19	-0.13	0.31	4

Table 9; Spectral Slope: Change in Spectral Slope after one incubation period with 95% confidence interval.

Sample	Initial Spec. Slope (nm^{-1})	Final Spec. Slope (nm^{-1})	Difference	P	n
AL reactor	0.0197	0.0191	+0.0006 ± 0.0004	0.08	10
DS reactor	0.0164	0.0161	+0.0003 ± 0.0001	<0.01	16
MS reactor	0.0168	0.0163	+0.0005 ± 0.0002	<0.01	18
HW reactor	0.0170	0.0168	+0.0002 ± 0.0001	0.02	20
AL batch	0.0198	0.0199	-0.0001 ± 0.0005	0.78	4
DS batch	0.0159	0.0163	-0.0004 ± 0.0003	0.03	4
MS batch	0.0162	0.0169	-0.0007 ± 0.0001	0.12	4
HW batch	0.0167	0.0163	+0.0005 ± 0.0003	0.02	4

Bacterial Growth Efficiency: Table 10 presents the BGE values from each batch culture. BGE on day one ranged from 2.3% in the algal culture to 55.8% for the headwater samples. The BGE for midstream and downstream were not significantly different as shown in Table 10 and Figure 11. Values were not constant across the 21 day incubation period, but no specific trend is evident. Maximum BGE occurred on day one for all sites except the algal culture, which seemed to increase and then level off after day 14. The greatest change in BGE occurred in the headwater site, which went from 55.8% on day one to 9.9% on day 7.

Table 10; BGE: Average (n= 4, ± 95% confidence interval) BGE values (%) measured using batch culture techniques.

Batch	BGE Day 1	BGE Day 7	BGE Day 14	BGE Day 21
Algal	2.3 ± 0.6	7.1 ± 1.6	15.0 ± 2.4	12.2 ± 3.2
Downstream	24.9 ± 5.0	5.9 ± 3.0	13.0 ± 6.7	3.1 ± 2.2
Midstream	20.9 ± 5.2	7.2 ±3.5	13.4 ± 5.2	8.6 ± 5.7
Headwater	55.8 ± 2.5	9.9 ± 3.1	9.4 ± 6.8	9.8 ± 6.0

Controls on BGE: As shown in Table 4, biolability increased as sampling site moved downstream. However, while a discernable trend was lacking, BGE was consistently highest in the headwaters (Table 10). Figure 12 displays the relationship between BGE and biolability. This inverse relationship is significant (r^2=0.4236, P=0.02) and the data points consist of 4 each from Algal and Downstream, 3 from Midstream, and one point for Headwater.

There was no significant relationship between initial DOC concentration and BGE. The influence of nutrients on BGE was also examined. Figure 13 shows the significant inverse relationship (r^2= 0.4217, P<0.01) between TDN and BGE, and Figure 14 shows the significant positive relationship between C:N and BGE (r^2= 0.6056, P<0.01), which explains a greater proportion of the variability in BGE data. Combined, these relationships suggest that N availability may be influencing BGE. There was no significant relationship between TDP, C:P, or N:P and BGE.

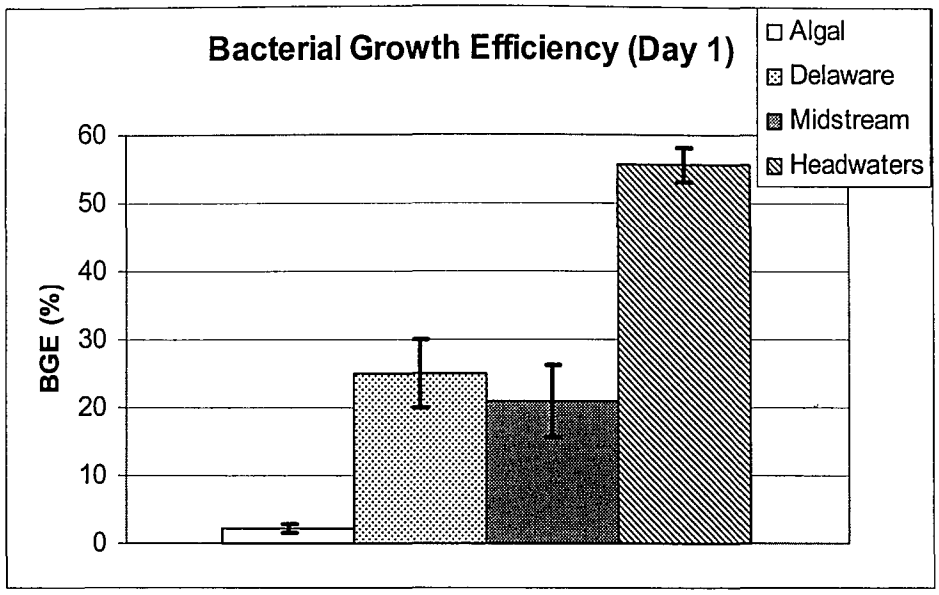

Figure 11: Bacterial growth efficiency on day 1 of the incubation varied between sites, but Delaware and Midstream were not significantly different.

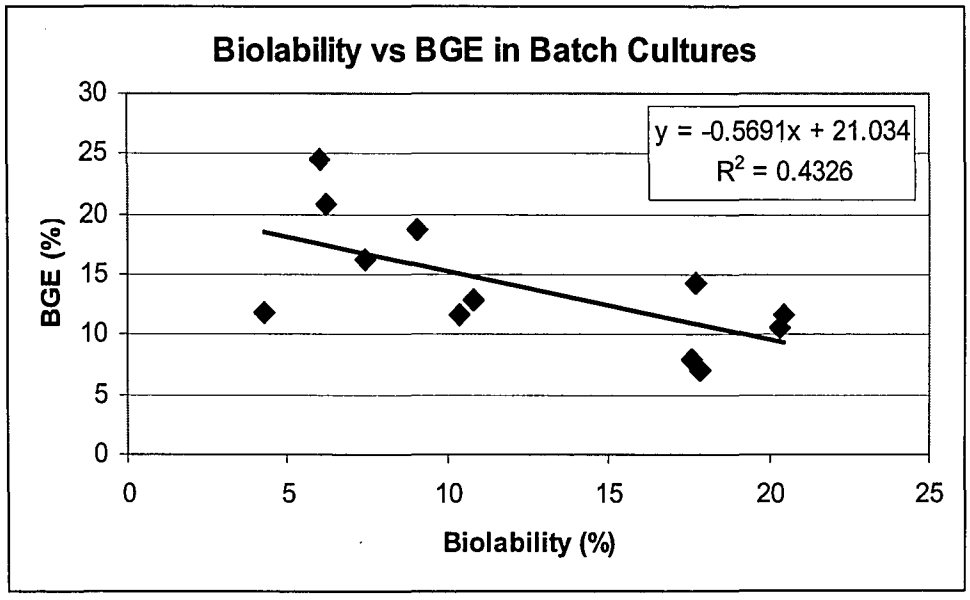

Figure 12: Biolability and BGE in the batch cultures showed a significant inverse relationship (P= 0.02, n=12).

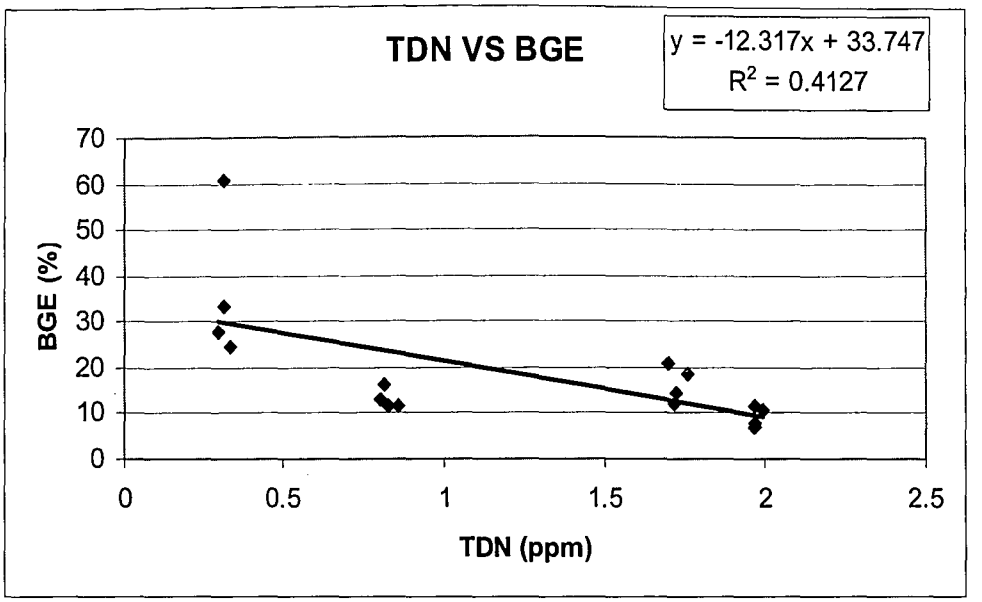

Figure 13: Initial TDN may be playing role in BGE regulation (P-value 0.007, n= 16).

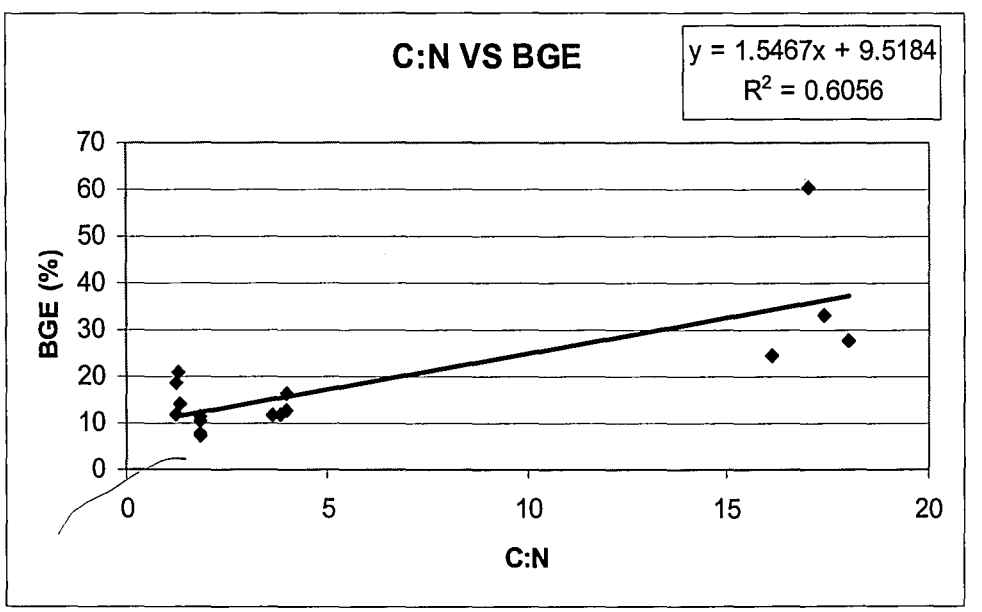

Figure 14: Initial C:N ratio may be playing a greater role in regulation of BGE (P= 0.0004, n=16).

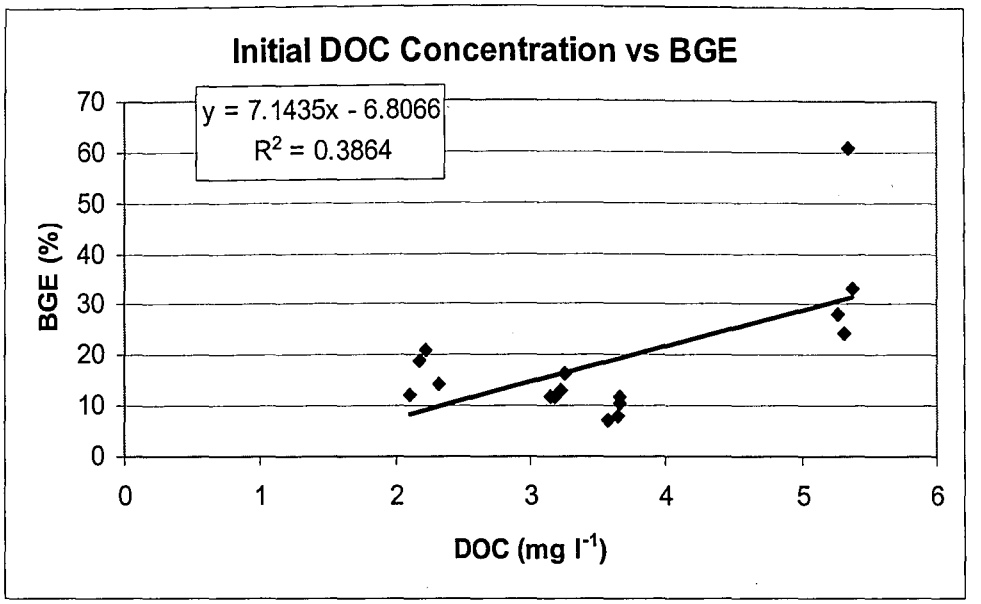

Figure 15: Bacterial growth efficiency was positively correlated with DOC concentration (P= 0.01, n=16).

Discussion: Differences in DOC concentration between sites are likely due to changes in production and consumption, as well as transport of DOC to the river. Additionally, the high concentrations from the headwater samples are likely due to high carbon flux from the surrounding watershed, which is dominated by forest and wetlands. This land use type would produce large amounts of humic material, which accounts for the bulk of total DOC (Wallis and Ladd 1983). These humic compounds are likely diluted with more autochthonous carbon downstream as river discharge increases and photosynthesis increases.

Spectrofluorometric measurements were taken to better understand the composition of DOC at each sampling site. This data is presented in Table 2. Downstream sites were expected to provide highly autochthonous DOC while more headwater samples were expected provide more allochthonous DOC. Measurements of absorption coefficients, spectral slope, F-ratio, and DOC-specific total fluorescence did show differences between sites suggesting that a variety of DOC was obtained. While a

general trend towards more allochthonous DOC in the headwaters was present, it was difficult to find a definitive autochthonous signal at downstream sites. Spectrofluorometric measurements provide a quick and easy index of DOC quality. However, more precise identification of DOC composition would require high performance liquid chromatography analysis as described by Lindroth and Mapper (1979), which unfortunately was not performed for this study.

Nutrient data (Table 3) shows distinct differences between sites. The river sample with the highest nutrient concentrations was the Midstream site with 1.88 ppm TDN and 36.9 ppb TDP. This is likely due to differences in land use upstream of this site as well as anthropogenic nutrient additions through point source and non-point source pollution. Standard deviations from the mean are also shown in Table 3. High SD values may be due to temporal variability in TDP or lack of replication. Small sample volume did not allow triplicate measurements as the method recommends. As a result, TDP values are highly variable and should be used only as a general indication of nutrient concentrations. Nutrient ratios are also presented in Table 3. While highly variable C:N and C:P ratios approach the Redfield Ratio with the exception of Headwater C:P which is significantly higher.

DOC biolability has also been used as a measure of DOC quality. As defined above, biolability is simply a measure of the fraction of the DOC pool which is easily consumed by a heterotrophic microbial community. Biolability was measured using both the batch culture technique and plug-flow bioreactors. As shown in Table 4, biolability increased from 8.21% for Headwater samples to 16.25% for Downstream samples when using plug-flow bioreactors. The results from batch cultures are also shown in Table 4,

and they again show an increase in biolability from 6.02% for Headwater samples to 8.24% for Downstream samples. These values approach the global average of 14% (Sondergaard and Middleboe 1995) as well as the range measured by Volk (16.5%-34.4%) in White Clay Creek in Pennsylvania (1997).

In addition to biolability measurements, spectrofluorometric measurements were used to determine which fraction of DOC was consumed. When considering all four of the spectrofluorometric measures it appears that a shift towards a more terrestrial signal occurs in both batch cultures and plug-flow bioreactors. This is shown by the increase in DOC-specific total fluorescence in Table 7 as well as the increase in spectral slope shown in Table 9. While allochthonous DOC was likely consumed as well (Kaplan 2008), this suggests that autochthonous DOC was preferentially consumed leaving behind the more terrestrial DOC. This matches the results of Kritzberg et al. (2004) who demonstrated that bacteria in lakes preferentially consumed fresh autochthonous DOC. It also suggests that both types of incubations are preferentially consuming the same fraction of DOC. This is especially important when comparing the two methods of measuring biolablity. This will be discussed further in Section 2.

Traditionally, DOC quality has been considered the dominant control over DOC biolability while DOC quantity has been shown to play a secondary role (Kaplan 1995). In this study DOC biolability was negatively correlated with initial DOC in bioreactors (Figure 6). However, initial DOC concentration explained only minimal variance (r^2 = 0.09) in DOC biolability, and this relationship only existed after removing Algal samples from bioreactor data. Batch cultures failed to show any significant relationship between initial DOC concentration and DOC biolability (Figure 7).

Del Giorgio and Cole (1998) point out that nutrient supply is likely to play a critical role in determining DOC biolability. Figures 8-10 show the influence of TDN and TDP on DOC biolability. Figure 8 shows a significant positive relationship ($P<0.01$, $n=64$, $r^2= 0.205$) between TDN and DOC biolability when measured in the bioreactors, and Figure 9 shows a significant negative relationship ($P<0.01$, $n=64$, $r^2= 0.1837$) between C:N and DOC biolability. Finally, Figure 10 shows the positive relationship ($P<0.01$, $n=62$, $r^2= 0.2465$) between N:P and DOC biolability. All three of these plots suggest that nutrient availability may play as much of role as DOC quantity in controlling DOC biolability. There was no significant relationship between TDP or C:P and DOC biolability. This may be due to the high variability in TDP measurements.

Bacterial growth efficiency was measured at each site using the batch cultures. Table 10 presents the BGE measurements for each site. BGE was highest in the headwaters and lowest in the Algal samples. Similar to biolability, overall trend was present since BGE at Midstream and Downstream were not statistically different as shown in Figure 11. BGE tended to be the highest on day one and then decreased and stabilized as the incubation period continued. This occurred in all 3 natural river samples but not for the Algal sample. This decrease in BGE after day one may be a result of initial consumption of high quality, labile DOC followed by consumption of more refractory DOC. However, this is contrary to the fact that BGE increased as DOC biolability decreased as shown in Figure 12. BGE was highest in the headwaters while DOC biolability was highest downstream. This may suggest that highly labile DOC consists of low energy molecules while the headwater DOC is high in energy. This would allow headwater BGE to be higher despite low biolability of DOC. Downstream

rapid consumption of low energy molecules could lead to high respiration rates with low production rates, which would result in lower BGE.

Nutrient availability was used to attempt to explain changes in BGE along the river course. Figure 13 shows the relationship between TDN and BGE. This significant negative relationship ($P<0.01$, $n=16$, $r^2= 0.4127$) suggests that as TDN increases BGE decreases. However, Figure 14 shows that there was a positive relationship between C:N and BGE ($P<0.01$, $n=16$, $r^2= 0.6056$). This suggests that increased nitrogen leads to lower BGE. However, it is unlikely that increased nitrogen causes a reduction in BGE. Published studies show the opposite trend, that increased nutrient availability should lead to increased BGE (Del Giorgio and Cole 1998). It is more likely that anthropogenic influences specific to this river system are causing a decrease in BGE as nitrogen increases. The Lehigh River receives sewage treatment plant outflow from numerous communities. These outflows likely contribute high nutrients concentrations and DOC to the system. The DOC in treatment plant outflow is likely to be highly degraded and composed of low energy composed. Additionally, increases in anthropogenic activities downstream are likely to discharge increasing amounts of toxin to the river. As a result, BGE may decrease due to an increase in low energy DOC or toxins and not an increase in nitrogen. Testing this hypothesis would require comparisons with natural streams with limited anthropogenic influences. No significant relationship was found between TDP or C:P and BGE.

Limitations and Conclusions: By obtaining samples from along the river course, it was expected that differences in DOC quality and biolability and BGE would be present. It was expected that the headwater DOC would be mostly terrestrial in origin while DOC

from the lower reaches would gradually become more autochthonous. The Algal source was used as an end point to compare to natural samples and was expected to be highly autochthonous in nature.

The endpoints used (Algal and Headwater) matched the expected results. Headwater was highly terrestrial and had low DOC biolability while Algal was highly autochthonous and had high DOC biolablity. However, the two intermediate samples did not provide a consistent trend. The Midstream samples were expected to be more terrestrial in nature while Downstream should have been more autochthonous. However, spectrofluorometric measurements were ambiguous and did not necessarily show this pattern. The lack of river continuum pattern could be due to numerous factors. As previously mentioned, it may be a result of overwhelming influence of the headwaters of the Delaware River on the Downstream site. While being downstream of the Midstream site, which was along the Lehigh River, the Downstream site is likely to be more highly controlled by characteristics of the Delaware River and not necessarily the headwaters of the Lehigh River.

Temporal as well as seasonal variability may have played a role. Unfortunately, it was not possible to sample each site on the same day, and the nature of the batch culture technique caused sampling dates to be months apart. The time between sampling likely lead to differences in physical and chemical water quality parameters including pH, temperature, DO, and discharge. All of which have the potential to influence DOC production, supply and therefore consumption and quality.

Additionally, anthropogenic influences may have altered DOC dynamics within the river system from what may be predicted by the River Continuum Concept. The

Lehigh and Delaware River watersheds have multiple dams, and are heavily affected by anthropogenic land use changes. These altered landscapes may have influenced the production, supply and availability of DOC. For example, deforestation leads to soil erosion, which allows for higher loading of terrestrial DOC to the river system. At the same time, non-point source nutrient inputs from farming operations may lead to increased algal production, which could lead to an increase in the supply of autochthonous DOC and a reduced influence of allochthonous DOC as found by Carpenter (1998, 2005). Municipal wastewater entering the river is also likely to alter the composition of the DOC pool. DOC from this source is likely to be highly processed and differ significantly in composition from natural DOC.

Finally, nitrogen and phosphorus data should be considered with caution. These analysis were performed on limited remaining water samples. As a result replication was not possible, which lead to increased variability in the results. Additionally, the phosphorus method used was scaled down allow analysis of limited samples. In addition to limiting replication this may have lead to misrepresentation of the total water sample.

Despite these issues, it is apparent that DOC quality and biolability is influenced by position in the watershed. This study also reinforces the idea that biolability is highly controlled by DOC quality while quantity plays a secondary roll. It appears that BGE is not controlled by DOC biolability, and nutrient data presented here fail to support the idea that increases in nutrient availability will lead to higher BGE. BGE may vary with trophic richness, but additional studies would be required to make such a conclusion from these results.

Biolability and BGE measurements suggest that bioenergetics in the headwaters of this system are limited by labile supply of carbon. BGE suggests that while headwater DOC may be refractory, microbes are able to consume a small fraction and produce biomass efficiently when they do so. Conversely, it appears downstream sites have adequate supplies of labile carbon, but these carbon compounds have low food quality and do not provide efficient production of biomass. As previously mentioned, this may be an anthropogenic influence on ecosystem energetics. It also suggests that increased supply of food quality compounds as well as toxins from municipal wastewater treatment plants may lead to reduced BGE in aquatic systems. An increase in toxins would lead to increased maintenance requirements. As a result, a higher proportion of DOC would be respired as CO_2, and a lower percentage would go directly to production of new biomass.

Section 2: Batch Cultures and Bioreactors: A comparison of results

Results: Table 11 presents DOC consumption rates in batch cultures and bioreactors. Consumption rates in bioreactors, calculated using a residence time of 3 hours based on flow rate and column volume, were consistently higher with values ranging from 0.09 mg l^{-1} hr^{-1} for Midstream samples to 0.48 mg l^{-1} hr^{-1} for Algal samples. Algal samples had the highest consumption rates in batch cultures as well with a rate of 0.00138 mg l^{-1} hr^{-1}. While consumption rates in the bioreactors and batch cultures were scaled differently there was a significant positive correlation between their values (r^2= 0.7118, $P<0.01$, n=16) as shown in Figure 16. Considering the mean residence time for the bioreactors (3 hours) and the incubation period of the batch cultures (21 days) it was possible to predict the batch culture incubation time required to consume an equivalent quantity of DOC as

was consumed by one pass through the bioreactors. These are shown in Table 11 and range from 21 days for Midstream samples to 44 days for Algal samples.

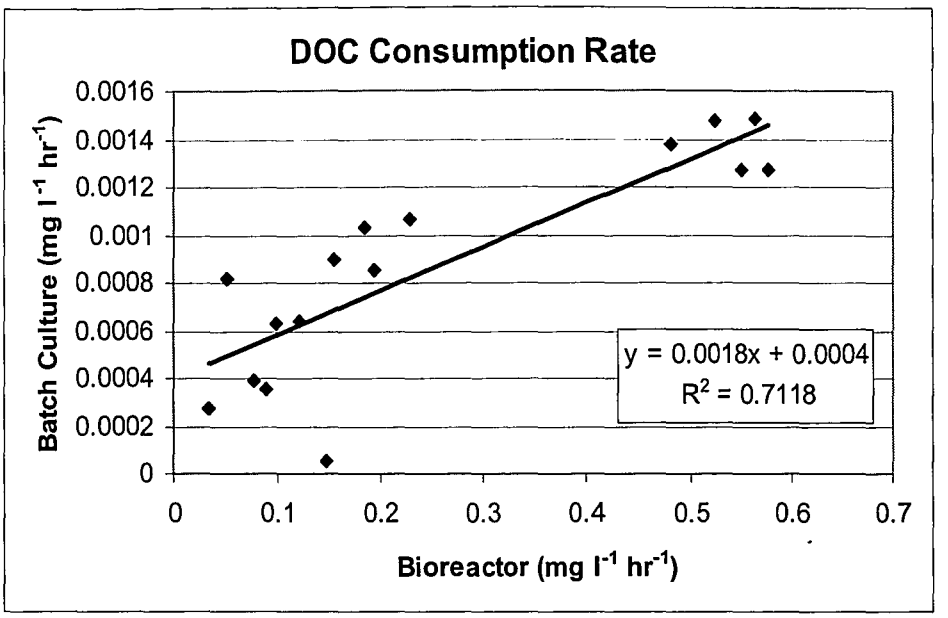

Figure 16: DOC consumption rate (calculated as total DOC consumption divided by total hours of incubation) the bioreactors and batch cultures was positively correlated ($n=16$, $P<0.01$).

Table 11; DOC Consumption Rate: Comparing consumption rates allows for the extrapolation of similar endpoints. The batch cultures would require 44 days to consume the amount of DOC consumed in one pass through the bioreactors with algal culture water. The 95% confidence intervals are presented for biolability.

Source	Batch DOC Cons. Rate (mg l^{-1} hr^{-1})	Bioreactor DOC Cons. Rate (mg l^{-1} hr^{-1})	Equivalent Batch Incubation (Days)	Batch DOC Biolability (%)	Bioreactor DOC Biolability (%)
Algal	0.00138	0.48	44	19.07 ± 1.51	36.96 ± 3.09
Downstream	0.00053	0.15	37	8.24 ± 2.96	16.25 ± 2.12
Midstream	0.00036	0.09	21	11.01 ± 6.77	13.66 ± 3.52
Headwaters	0.00064	0.15	29	6.02	8.21 ± 1.15

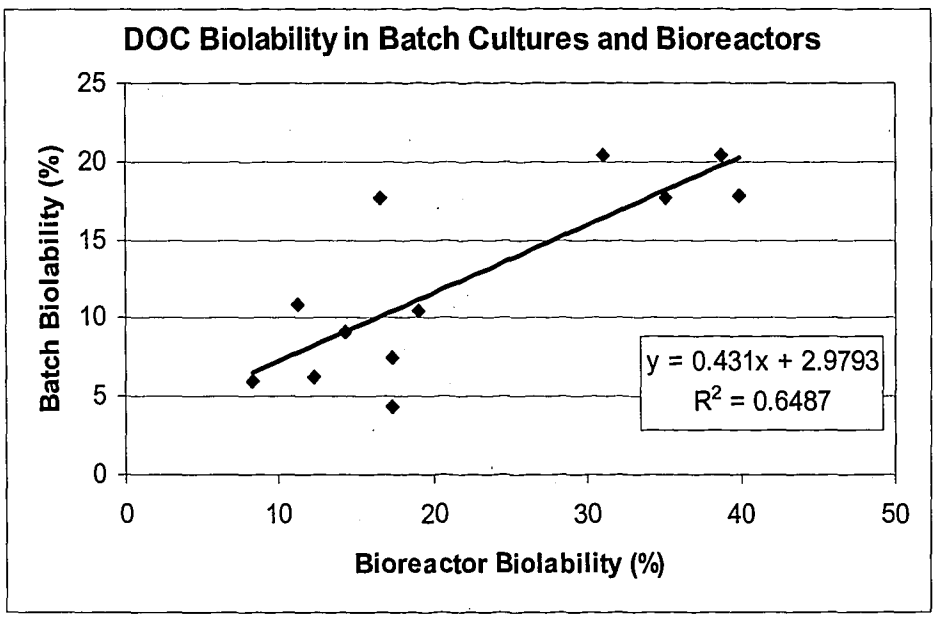

Figure 17: DOC biolability in batch cultures was positively correlated with biolability in bioreactors (n=12, P<0.01).

DOC biolability is also shown in Table 11. As previously mentioned, biolability calculated using the bioreactors was significantly higher than those calculated using the batch cultures. Biolability in the bioreactors ranged from 8.21 % for Headwater samples to 36.96 % for Algal samples. Headwater samples had the lowest BGE in batch cultures as well with 6.02 %, and Algal samples again had the highest BGE at 19.07%. As shown in Figure 17, despite significant differences biolability measured with the batch cultures was positively correlated with that measured in the bioreactors (r^2= 0.6487, P<0.01, n= 12).

Like DOC biolability and consumption rate, bacterial respiration rates were significantly higher in the bioreactors. However, as shown in Figure 18 they were also positively correlated (r^2= 0.6186, P<0.01, n= 16) with those measured in the batch cultures. Figure 19 shows the negative correlation between bacterial respiration and BGE (r^2= 0.8007, n=16, P<<0.01).

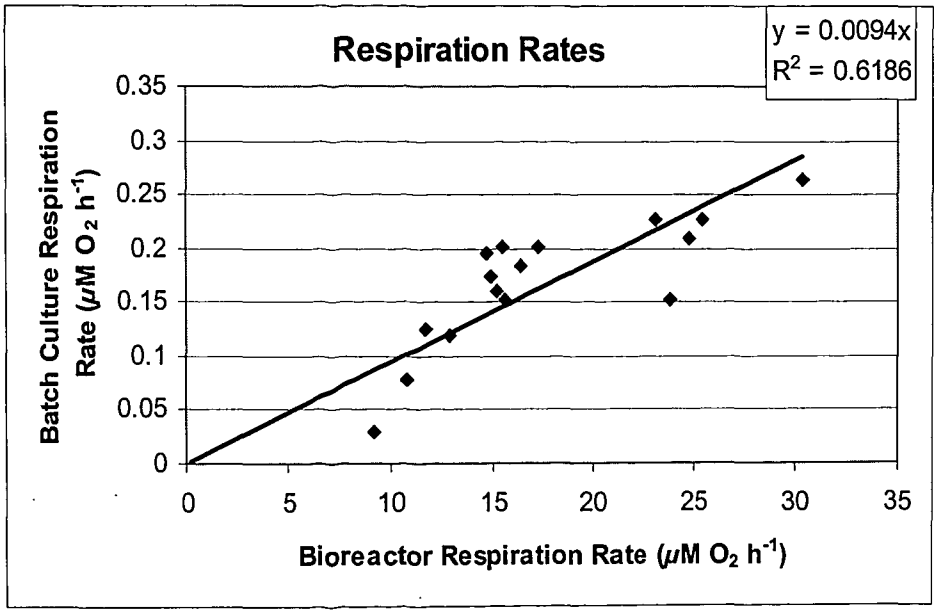

Figure 18: A significant (n=16, P<0.01) relationship between respiration rates in the bioreactors and batch cultures may allow prediction of batch culture respiration using bioreactor methods.

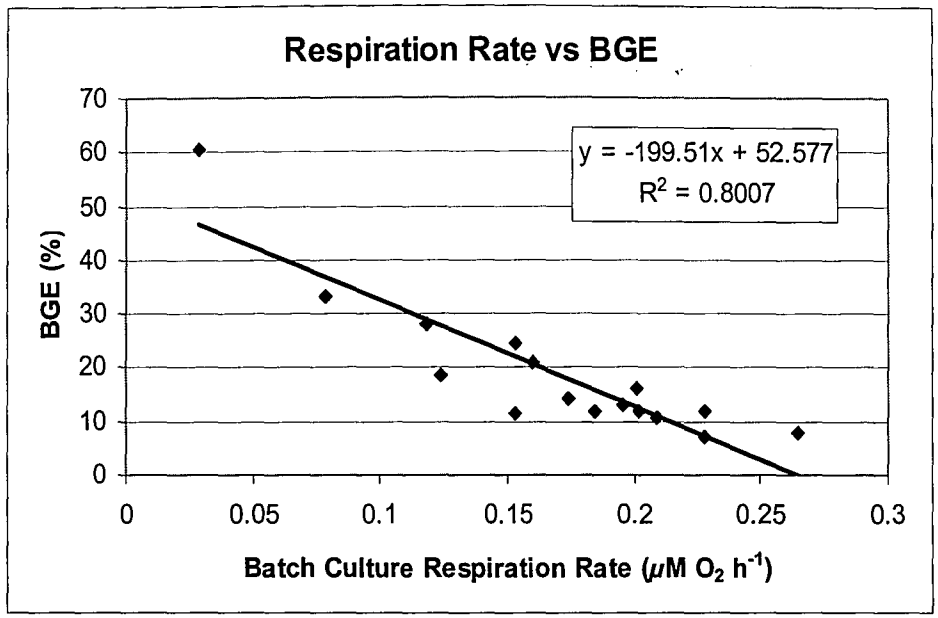

Figure 19: A significant (n=16, P<<0.01) relationship between respiration rate and BGE could allow prediction of BGE from respiration measurements.

Discussion: It was hypothesized that batch cultures and bioreactors would provide similar results for DOC biolability, and that similarities between the methods would allow an intercalibration. While DOC biolability was significantly higher when measured with the bioreactors it was strongly correlated with biolability measure using the batch cultures. The higher biolability values in the bioreactors are likely due to a higher biomass of heterotrophic microbes. By design, the bioreactors provide large surface area, which allows microbial communities to form dense biofilms (Kaplan and Newbold 1995). In contrast, the batch cultures favor planktonic bacteria over biofilms and tend to exclude the production of complex bacterial communities (Sondergaard and Worm 2001). As a result, overall microbial activity is higher in the bioreactors, which is also supported by higher DOC consumption (Table 11) and bacterial respiration rates (Figure 16). Additionally, batch cultures suffer from "container effect", which can

exclude natural microbial processes and results can vary substantially from what would be measured in situ (Søndergaard and Worm 2001).

Table 11 also provides suggested incubation periods for batch cultures based on DOC consumption rates. The incubation time used for these measurements was 21 days in the batch cultures and was similar to the traditional range of 5-20 days (Søndergaard and Worm 2001). It appears this 21 day incubation was equivalent to one pass through the bioreactors for Midstream samples. However, Algal samples would require twice the incubation period (44 days), and Downstream and Headwater samples would require incubation periods of 37 and 29 days respectively. While these estimates assume linear DOC consumption rates, which are more likely exponential, they provide estimates that suggest future comparisons between batch cultures and bioreactors would benefit from longer batch incubation periods.

The data presented here show it is possible to predict batch culture biolability with bioreactor measurements, which will only be improved with additional simultaneous measurements from batch cultures and bioreactors. This provides the advantage of reduced incubation periods and more efficient measurements of biolability. Additionally, bioreactors likely provide a better estimate of DOC biolability for lotic ecosystems by closely mimicking ecosystem dynamics including the production of biofilms. This will ultimately lead to biolability measurements that more closely predict *in situ* conditions. The simple linear regression in Figure 17 shows that these types of predictions are possible. While the sample size is small (n= 12) this data shows a significant positive relationship ($P<0.01$, $r^2= 0.6487$) between biolability measurements. Increases in sample

number should only strengthen this relationship and improve the predictive power of such a comparison.

In addition to predicting biolability, it would be extremely useful to be able to predict BGE using bioreactors. As previously mentioned it is not possible to measure bacterial production and thus BGE when using bioreactors. However, by taking simultaneous measurements from bioreactors and batch cultures it may be possible to create a model to predict BGE through bioreactor measurements. While bacterial production measurements are not possible with bioreactors, it is possible to measure bacterial respiration in bioreactors as well as batch cultures. Simultaneous measurements of bacterial respiration from each method provide the opportunity for calibration. Figure 18 shows the significant relationship (r^2= 0.6186, n=16, P<0.01) between bacterial respiration in the bioreactors and batch cultures. As a result, it may be possible to predict batch culture respiration rates from bioreactor measurements. If so, these predicted respiration rates could be used to predict BGE, which is strongly correlated with measured bacterial respiration as shown in Figure 19 (r^2= 0.8007, n=16, P<<0.01). Figure 19 is a regression of measured respiration rates in batch cultures and measured BGE in batch cultures. The combination of Figures 19 and 20 may provide a simple way to predict BGE by measuring bacterial respiration in bioreactors. This would eliminate laborious bacterial production measurements.

Limitations and Conclusions: The results presented here suggest that it may be possible to predict BGE using bioreactors. It also shows that DOC biolability is significantly greater when measured using bioreactors, but there is a significant correlation with biolability measured with batch culture techniques. Data presented here

represent the first attempt in the literature to quantitatively relate biolability estimates using different techniques. Although the scale is different for the two techniques, they provide identical rank order estimates of relative DOC biolability. Furthermore, the similarity between the biofilm in the reactors and in natural stream ecosystems suggest that the higher biolability values of bioreactors may be more indicative of actual in situ values.

Literature Cited:

Amon, R.M.W., R. Benner. 1996. Bacterial Utilization of Different Size Classes of Dissolved Organic Matter. Limnology and Oceanography 41: 41-45.

Benner R, Lay J, K'nees E, Hodson RE. 1998. Carbon conversion efficiency for bacterial growth on lignocellulose: Implications for detritus-based food webs. Limnology Oceanography 33: 1514–26.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications 14: 839-854.

Carpenter, S.R. J.J. Cole, M.L. Pace, M. Van de Bogert, D.L. Bade, D. Bastviken, C.M. Gille, J.R. Hodgson, J.F. Kitchell, and E.S. Kritzberg. 2005. Ecosystem Subsidies: Terrestrial Support of Aquatic Food Webs From 13C Addition to Contrasting Lakes. Ecology 86: 2737-2750.

Cole, J.J., M.L. Pace. Why Measure Bacterial Production? A Reply to the Comment by Jahnke and Craven. 1995. Limnology and Oceanography 40: 441-444.

Del Giorgio, Paul A., Jonathon J. Cole. Bacterial Growth Efficiency in Natural Aquatic Ecosystems. Annual Review of Ecological Systems. 1998. 29: 503-41.

Del Giorgio, Paul A. "Quantifying Changes in Bacterial Growth Efficiency (BGE): a Methods Guide." University of New Hampshire. University of New Hampshire. 2 Nov. 2006 <http://ciceet.unh.edu/news/newellMethods/>.

Del Giorgio, Paul A., M.L. Pace. 2008. "Relative Independence of Dissolved Organic Carbon Transport and Processing in a Large Temperate River: The Hudson River as Both Pipe and Reactor." Limnology and Oceanography 53: 185-197.

Edwards, R. T.. and J. L. Meyer. 1987. Bacteria as a food source for black fly larvae in a blackwater river. Journal of the North American Benthological Society 6: 241-250.

Edwards. R. T., and J. L. Meyer. 1990. Bacterivory by a deposit-feeding mayfly (Stenonema spp.). Freshwater Biology 24: 453-462.

Findlay, S., M. L. Pace. D. Lints, and K. Howe. 1992. Bacterial metabolism of organic carbon in the tidal freshwater Hudson estuary. Marine Ecology Progress Series 89: 147-153.

Frias, J., F. Ribas and F. Lucena. 1992. A method for the measurement of biodegradable organic carbon in waters. Water Resources 26: 255-258.

Jahnke, R.A., D.B. Craven. 1995. Quantifying the Role of Heterotrophic Bacteria in the Carbon Cycle: A Need for Respiration Rate Measurements. Limnology and Oceanography 40: 436-441.

Kaplan L. A. and T.L. Bott. 1982. Diel Fluctuations of DOC Generated by Algae in a Piedmont Stream. Limnology and Oceanography 27: 91-100.

Kaplan L. A. and J. D. Newbold. Biogeochemistry of Dissolved Organic Carbon Entering Streams. In: Ford, T.E., editor. Aquatic Microbiology: an Ecological Approach. Oxford: Blackwell Scientific. 1993: 139-165.

Kaplan L. A. and J. D. Newbold. 1995. Measurement of Stream Biodegradable Dissolved Organic Carbon with a Plug-Flow Bioreactor. Water Research 29: 2696-2706.

Kaplan, L. A., F. Ribas, J. C. Joret, C. Volk, J. Frias, and F. Lucena. 1996. Measurement of Biodegradable Organic Matter with Biofilm Reactors. AWWA Research Foundation: 69.

Kaplan, L.A., T.N. Wiegner, J.D. Newbold, P.H. Ostrom and H Gandhi. 2008. Untangling the complex issue of dissolved organic carbon uptake: a stable isotope approach. Freshwater Biology 53: 855-864.

Kim, S., L.A. Kaplan, P.G. Hatcher. 2006. Biodegradable dissolved organic matter in a temperate and tropical stream determined form ultra-high resolution mass spectrometry. Limnology and Oceanography 51: 1054-1063.

Kirk, J., AND OTHERS. 1994. Measurements of UV-B radiation in two freshwater lakes: an instrument comparison. Ergeb. Limnol. 43: 71-99.

Kritzberg, E.S., J.J. Cole, M.M. Pace, W. Graneli and D.L. Bade. 2004. Autochthonous vs. Allochthonous Carbon Sources to Bacteria: Results from Whole-lake 13C Experiments. Limnology and Oceanography 49: 588-596.

Kritzberg, E.S., J.J. Cole, M.M. Pace, W. Graneli and D.L. Bade. 2005. Does Autochthonous Primary Production Drive Variability in Bacterial Metabolism and Growth Efficiency in Lakes Dominated by Terrestrial C inputs? Aquatic Microbial Ecology 38: 103-111.

Kroer, N. 1993. Bacterial Growth Efficiency on Natural Dissolved Organic Matter. Limnology and Oceanography 38: 1282-1290.

Lindroth, P., and K. Mopper. 1979. Higher performance liquid chromatographic determination of subpicomole amounts of amino acids by precolumn fluorescence derivitization with *o*-phthaldialdehyde. Anal. Chem. 51: 167-1674.

Lucena, F., J. Frias and F. Ribas. 1990. A new dynamic approach to the determination of biodegradable dissolved organic carbon in water. Environmental Technology 12: 343-347.

Meyer JL, Edwards RT, Risley R. 1987. Bacterial growth on dissolved organic carbon from a blackwater river. Microb. Ecol. 13:13–29.

McKnight, D.M. and K.E. Bencala. 1990. The Chemistry of Iron, Aluminum, and Dissolved Organic Material in Three Acidic, Metal-enriched, Mountain Streams as Controlled by Watershed and In-stream Processes. Water Resources Research 26: 3087-100.

McKnight, D.M., E.L. Boyer, P.T. Doran, T. Kulbe, D.T. Anderson. 2001. Spectrofluorometric Characertization of Dissolved Organic Matter for Indication of Precursor Organic Material and Aromaticity. Limnology and Oceanography 46: 38-48.

Meyer, J.L. Production and Utilization of Dissolved Organic Carbon in Riverine Ecosystems. In: Perdue, E.M., E.T. Gjessing editors. Organic Acids in Aquatic Ecosystems. Chichester (UK): John Wiley and Sons. 1990 p. 281-299.

Meyer, J.L., J. O'Hop. 1983. Leaf-Shredding Insects as a Source of Dissolved Organic Carbon in Headwater Streams. American Midland Naturalist: 175-183.

Meyer, J.L. J. Bruce Wallace, Sue L. Eggert. 1998. Leaf Litter as a Source of Dissolved Organic Carbon in Streams. Ecosystems 1: 240-249.

Meyer, J.L. 1994. The Microbial Loop in Flowing Waters. Microbial Ecology 28: 195-199.

Morris, D.P., H. Zagarese, C.E. Williamson, E.G. Balseiro, B.R. Hargreaves, B. Modenutti, R. Moeller, and C. Queimalinos. 1995. The Attenuation of Solar UV Radiation in Lakes and the Role of Dissolved Organic Carbon. Limnology and Oceanography 40: 1381-1391.

Morris, D.P. and B.R. Hargreaves. 1997. "The role of photochemical degradation of dissolved organic carbon in regulating the UV transparency of three lakes on the Pocono Plateau." Limnolology Oceanography 42: 239-249.

Oliver, B.G., E.M. Thurman, R.L Malcolm. 1983. The Contribution of Humic Substances to the Acidity of Colored Natural Waters. Geochim. Cosmochim Acta 47: 2031-2035.

Parsons, Timothy R., Yoshiaki Maita, and Carol M. Lalli. A Manual of Chemical and Biological Methods for Seawater Analysis. Oxford: Pergamon P, 1984. 135-142.

Petit, M., P. Servais, P. Lavandier. 1999. Bacterial Production Measured by Luecine and Thymadine Incorporation Rates in French Lakes. Freshwater Biology 42: 513-524.

Reimann, Lasse and Morten Sondergaard. 2004. Profiles of Bacterial Community Composition and Metabolic Potential through a Plug-Flow Bioreactor fed with Lake Water. Journal of Plankton Research 26: 973-978.

Schindler, A.T., P.J. Curtis. 1997. The Role of DOC in Protecting Freshwaters Subjected to Climatic Warming and Acidification from UV Exposure. Biogeochemisrty 36: 1-8.

Scholz, A.T., R.M. Huralt, J.C. Cooper, A.D. Haslet. 1976. Imprinting to Chemical Cues: the Basis for Home Stream Selection in Salmon. Science 192: 1247-1249.

Sharp, J.H., AND OTHERS. 1993. Procedures subgroup report. Marine Chemistry. 41: 37-49.

Solorzano, L. and J. Sharp. 1980. Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnology and Oceanography 25: 754-758.

Søndergaard, M., M. Middleboe. 1995. A cross-system analysis of labile dissolved organic carbon. Marine Ecol. Prog. Ser. 118: 283-294.

Søndergaard, M., Jakob Worm. 2001. Measurement of Biodegradable Dissolved Organic Carbon (BDOC) in Lake Water with A Bioreactor. Water Research 35: 2505-2513.

Vannote, R.L., G.W. Minshall, K.W. Cummings, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Volk, C.J., C.B. Volk, L.A. Kaplan. 1997. Chemical composition of biodegradable dissolved organic matter in streamwater. Limnology and Oceanography 42: 39-44.

Wallis, P.M. and T.I. Ladd. 1983. Organic biogeochemistry of groundwater at a mountain coal mine. Geomicrobiol. J. 3: 49-78.

Wetzel, R.G. 1992. Gradient-dominated ecosystems: sources and regulatory functions of dissolved organic matter in freshwater systems. Hydrobiologia 229: 181-198.

Wetzel, Robert G. Limnology: Lake and River Ecosystems. 3rd ed. San Diego: Academic P, 2001. 139-141.

Williams, C.W., D.P. Morris, M.L. Pace, O.G. Olson. 1999. Dissolved organic Carbon and Nutrients as Regulators of Lake Ecosystems: Resurrection of a more Integrated Paradigm. Limnology and Oceanography 44: 795-803.

Appendix:

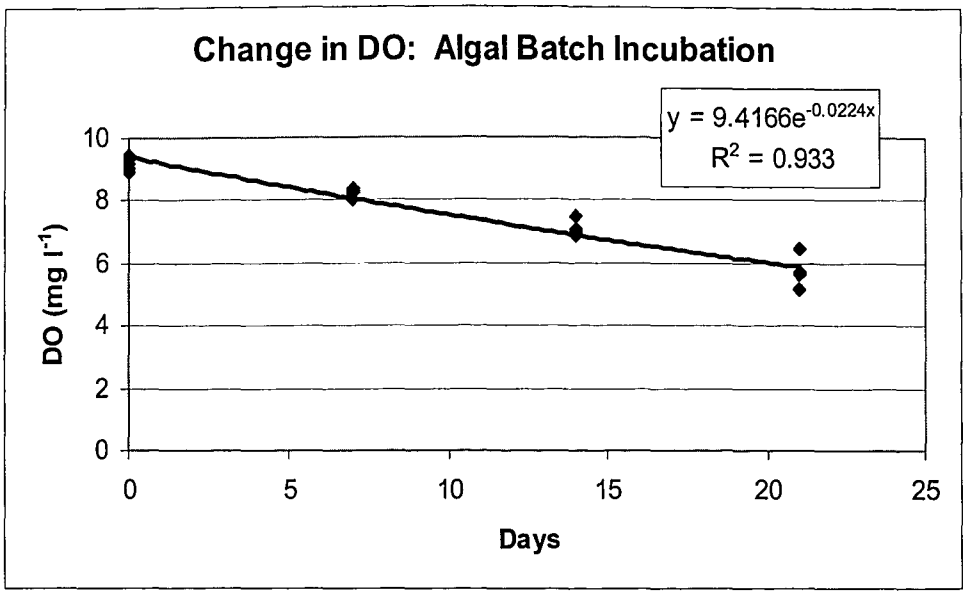

Figure 1: Example plot of how daily respiration rate was calculated. Daily oxygen consumption was then converted to μM C l^{-1} h^{-1} using a respiratory quotient of 1.

Table 1: Algal sample water chemistry

Method	Date	ID	DOC (mg l^{-1})	pH	DIC (μM C l^{-1})	DO (mg l^{-1})	TDN (ppm)	TDP (ppb)
Batch	7/18/07	A1	3.66	7.94	65.68	9.04	1.99	225.3
Batch	7/18/07	B1	3.64	7.85	60.90	9.46	1.97	31.1
Batch	7/18/07	C1	3.65	7.87	63.93	8.92	1.97	18.0
Batch	7/18/07	D1	3.57	7.93	67.06	9.35	1.97	8.3
Batch	7/25/07	A7	3.56	7.78	64.10	8.36	1.97	9.3
Batch	7/25/07	B7	3.79	7.85	69.57	8.02	2.00	11.9
Batch	7/25/07	C7	3.49	7.68	68.13	8.29	2.01	247.0
Batch	7/25/07	D7	3.59	7.86	73.41	8.26	2.00	8.8
Batch	8/1/07	A14	3.39	6.75	68.15	7.47	1.94	12.2
Batch	8/1/07	B14	3.05	6.87	73.63	6.88	1.99	11.1
Batch	8/1/07	C14	3.04	6.99	72.82	6.97	2.00	6.8
Batch	8/1/07	D14	3.31	7.09	75.95	7.04	2.00	180.5
Batch	8/8/07	A21	2.92	6.73	69.30	5.68	1.98	5.7
Batch	8/8/07	B21	3.00	6.83	75.80	5.19	2.01	7.1
Batch	8/8/07	C21	2.90	6.96	73.13	6.45	2.02	8.5
Batch	8/8/07	D21	2.94	7.04	78.04	5.68	2.00	5.2
Bioreactor Source	7/17/07	C	3.82	7.66	57.19	10.66	2.23	
Bioreactor Source	7/17/07	D	3.62	7.96	56.64	10.30	2.17	
Bioreactor Source	7/19/07	C	3.57	7.03	57.99	10.48	1.93	262.5
Bioreactor Source	7/19/07	D	3.65	7.12	64.62	10.12	1.98	105.8
Bioreactor	7/20/07	C	3.76	7.09	60.52	9.87	1.87	7.0

Source								
Bioreactor Source	7/20/07	D	3.75	7.17	60.64	9.46	1.88	228.3
Bioreactor Source	7/20/07(1)	C	4.15	7.20	62.86	10.07	1.70	8.0
Bioreactor Source	7/20/07(1)	D	4.15	7.45	64.96	9.47	1.67	4.7
Bioreactor Source	7/24/0(2)	C	4.24	7.26	64.41	9.99	1.68	235.5
Bioreactor Source	7/24/072)	D	4.08	7.42	67.00	10.03	1.64	5.8
Bioreactor Outflow	7/17/07	C	2.80	6.94	61.57	8.31	2.08	
Bioreactor Outflow	7/17/07	D	2.34	7.37	71.89	7.90	2.01	1.8
Bioreactor Outflow	7/19/07	C	2.48	6.35	68.64	8.06	1.85	7.4
Bioreactor Outflow	7/19/07	D	2.20	6.40	77.09	7.97	1.84	
Bioreactor Outflow	7/20/07	C	2.41	6.32	67.41	7.88	1.79	201.8
Bioreactor Outflow	7/20/07	D	2.19	6.44	77.93	6.55	1.77	5.3
Bioreactor Outflow	7/24/07(1)	C	2.58	6.47	72.04	7.23	1.56	4.4
Bioreactor Outflow	7/24/07(1)	D	2.42	6.59	77.19	6.55	1.56	180.1
Bioreactor Outflow	7/24/07(2)	C	2.55	6.61	69.84	7.45	1.57	14.7
Bioreactor Outflow	7/24/07(2)	D	2.43	6.69	78.26	6.66	1.58	3.5

Table 2: Downstream sample water chemistry

Method	Date	ID	DOC (mg l^{-1})	pH	DIC (μM C l^{-1})	DO (mg l^{-1})	TDN (ppm)	TDP (ppb)
Batch	10/17/07	A1	3.19	7.11	72.05	11.66	0.83	61.4
Batch	10/17/07	B1	3.22	7.16	74.93	11.36	0.80	41.1
Batch	10/17/07	C1	3.26	7.12	73.91	11.30	0.81	
Batch	10/17/07	D1	3.16	7.24	71.77	11.46	0.86	8.9
Batch	10/24/07	A7	3.02	6.78	72.36	9.51	0.86	87.6
Batch	10/24/07	B7	3.05	6.78	73.49	9.71	0.84	25.8
Batch	10/24/07	C7	3.09	6.89	73.66	9.24	0.89	58.0
Batch	10/24/07	D7	3.10	6.86	75.96	9.87	0.85	1.8
Batch	10/31/07	A14	3.03	6.61	72.46	8.44	0.82	38.9
Batch	10/31/07	B14	3.02	6.69	76.51	8.92	0.83	44.2
Batch	10/31/07	C14	3.01	6.81	75.26	8.47	0.85	50.9
Batch	10/31/07	D14	2.96	6.80	77.50	8.97	0.86	67.5
Batch	11/7/07	A21	2.86	6.45	78.01	8.40	0.84	75.9
Batch	11/7/07	B21	2.87	6.54	80.23	8.20	0.86	9.7
Batch	11/7/07	C21	3.01	6.67	76.56	8.06	0.84	83.1
Batch	11/7/07	D21	3.02	6.61	77.41	7.79	0.84	41.7
Bioreactor Source	10/15/07	A	2.42	6.95	60.62	12.38	0.86	43.2
Bioreactor Source	10/15/07	B	2.53	7.01	61.88	12.38	0.82	41.4
Bioreactor Source	10/15/07	C	2.35	7.09	61.70	12.23	0.83	52.1
Bioreactor Source	10/15/07	D	2.54	7.10	63.72	12.32	0.81	52.2
Bioreactor Source	10/15/07(2)	A	2.42	7.14	64.63	12.02	0.91	19.5
Bioreactor Source	10/15/07(2)	B	2.40	7.17	65.90	11.82	0.87	71.3
Bioreactor Source	10/15/07(2)	C	2.43	7.06	64.23	11.86	0.85	36.5
Bioreactor Source	10/15/07(2)	D	2.40	7.05	66.85	11.98	0.89	14.8
Bioreactor Source	10/17/07(1)	A	3.34	7.31	66.34	11.86	0.82	21.2
Bioreactor Source	10/17/07(1)	B	3.18	7.33	69.32	11.37	0.82	62.4
Bioreactor Source	10/17/07(1)	C	3.36	7.17	67.51	11.16	0.83	15.6
Bioreactor Source	10/17/07(1)	D	3.14	7.12	70.02	12.09	0.84	4.1
Bioreactor Source	10/17/07(2)	A	3.11	7.19	68.35	11.91	0.85	13.8
Bioreactor Source	10/17/07(2)	B	3.26	7.22	70.77	11.82	0.81	7.7
Bioreactor Source	10/17/07(2)	C	3.16	7.26	68.78	11.79	0.83	66.2
Bioreactor Source	10/17/07(2)	D	3.12	7.22	70.45	11.88	0.86	56.3

Bioreactor Outflow	10/15/07	A	1.96	6.96	66.41	10.26	0.83	29.9
Bioreactor Outflow	10/15/07	B	2.13	6.89	68.59	10.37	0.81	22.7
Bioreactor Outflow	10/15/07	C	1.95	7.03	65.23	10.75	0.81	56.0
Bioreactor Outflow	10/15/07	D	1.93	6.96	67.77	11.30	0.81	49.9
Bioreactor Outflow	10/15/07(2)	A	2.08	6.95	66.99	10.55	0.83	28.4
Bioreactor Outflow	10/15/07(2)	B	2.20	6.82	71.77	10.16	0.74	92.3
Bioreactor Outflow	10/15/07(2)	C	2.16	6.91	70.21	10.50	0.75	42.5
Bioreactor Outflow	10/15/07(2)	D	2.12	6.97	71.72	10.51	0.85	17.6
Bioreactor Outflow	10/17/07(1)	A	2.65	7.02	72.59	9.78	0.84	47.0
Bioreactor Outflow	10/17/07(1)	B	2.54	6.97	75.25	9.26	0.87	82.8
Bioreactor Outflow	10/17/07(1)	C	2.86	6.86	74.79	9.26	0.81	70.6
Bioreactor Outflow	10/17/07(1)	D	2.72	6.90	74.54	9.30	0.86	7.7
Bioreactor Outflow	10/17/07(2)	A	2.55	6.89	72.63	10.17	0.86	8.7
Bioreactor Outflow	10/17/07(2)	B	2.58	6.93	75.86	10.78	0.87	10.3
Bioreactor Outflow	10/17/07(2)	C	2.58	6.96	72.13	10.28	0.84	12.3
Bioreactor Outflow	10/17/07(2)	D	2.76	7.00	74.97	10.48	0.82	20.5

Table 3: Midstream sample water chemistry

Method	Date	ID	DOC (mg l^{-1})	pH	DIC (μM C l^{-1})	DO (mg l^{-1})	TDN (ppm)	TDP (ppb)
Batch	9/19/2007	A1	2.18	7.11	94.78	10.21	1.76	127.2
Batch	9/19/2007	B1	2.32	7.18	96.36	11.03	1.72	121.9
Batch	9/19/2007	C1	2.23	7.10	94.92	10.46	1.70	120.7
Batch	9/19/2007	D1	2.11	7.24	98.07	11.37	1.71	162.8
Batch	9/26/2007	A7	1.98	6.96	95.48	9.19	1.75	198.8
Batch	9/26/2007	B7	2.04	6.99	93.69	9.13	1.73	
Batch	9/26/2007	C7	1.96	6.94	94.48	9.28	1.73	80.5
Batch	9/26/2007	D7	2.07	7.05	96.19	9.69	1.75	78.7
Batch	10/3/2007	A14	1.99	6.79	92.64	8.22	1.83	75.7
Batch	10/3/2007	B14	2.23	6.90	95.51	8.09	1.67	76.7
Batch	10/3/2007	C14	1.94	6.80	91.44	8.20	1.83	78.0
Batch	10/3/2007	D14	1.95	6.94	93.52	8.35	1.75	88.5
Batch	10/10/2007	A21	1.98	6.71	93.79	8.20	1.71	84.3
Batch	10/10/2007	B21	1.91	6.82	98.72	8.22	1.69	87.2
Batch	10/10/2007	C21	2.09	6.78	94.92	7.88	1.69	83.3
Batch	10/10/2007	D21	2.14	6.94	97.40	8.40	1.69	100.4
Bioreactor Source	9/8/07(1)	C	1.63	7.41	95.11	10.60	2.35	120.6
Bioreactor Source	9/8/07(1)	D	1.82	7.56	98.45	10.01	2.51	118.0
Bioreactor Source	9/8/07(2)	C	1.66	7.62	97.30	10.84	2.77	197.5
Bioreactor Source	9/8/07(2)	D	1.85	7.70	98.38	11.09	2.64	138.0
Bioreactor Source	9/9/07(1)	C	1.99	7.61	97.94	10.85	1.90	144.2
Bioreactor Source	9/9/07(1)	D	1.86	7.85	101.15	10.91	1.89	130.9
Bioreactor Source	9/10/2007	C	1.88	7.39	91.91	9.94	1.60	98.9
Bioreactor Source	9/10/2007	D	1.86	7.41	91.75	9.94	1.53	125.5
Bioreactor Source	9/15/2007	C	1.72	7.16	98.26	9.22	1.87	147.0
Bioreactor Source	9/15/2007	D	1.78	7.23	100.98	10.19	1.87	151.1
Bioreactor Source	9/17/2007	C	2.02	7.20	73.19	11.70	1.30	90.7
Bioreactor Source	9/17/2007	D	2.04	7.15	75.77	12.02	1.27	114.5
Bioreactor Source	9/19/2007	C	2.30	7.35	89.17	10.17	1.69	105.6
Bioreactor Source	9/19/2007	D	2.14	7.34	95.93	11.32	1.76	111.1
Bioreactor Source	9/20/2007	C	2.15	7.56	96.62	11.25	1.86	158.9
Bioreactor Source	9/20/2007	D	2.02	7.69	98.27	11.55	1.87	144.9

Bioreactor Source	9/20/2007(2)	C	1.95	7.65	97.65	10.64	1.89	165.9
Bioreactor Source	9/20/2007(2)	D	2.00	7.79	96.86	10.69	1.88	130.3
Bioreactor Outflow	9/8/07(1)	C	1.61	7.32	98.14	9.89	2.60	125.7
Bioreactor Outflow	9/8/07(1)	D	1.43	7.44	105.42	8.74	2.76	129.8
Bioreactor Outflow	9/8/07(2)	C	1.43	7.46	99.21	9.74	2.49	142.6
Bioreactor Outflow	9/8/07(2)	D	1.62	7.49	107.62	9.69	1.89	125.7
Bioreactor Outflow	9/9/07(1)	C	1.67	7.49	99.23	9.56	1.85	122.9
Bioreactor Outflow	9/9/07(1)	D	1.71	7.47	108.03	9.37	1.84	165.9
Bioreactor Outflow	9/10/2007	C	1.40	7.28	95.56	8.04	1.58	102.5
Bioreactor Outflow	9/10/2007	D	1.57	7.21	100.73	8.36	1.50	86.4
Bioreactor Outflow	9/15/2007	C	1.74	7.05	99.66	8.63	1.84	132.4
Bioreactor Outflow	9/15/2007	D	1.51	7.07	106.12	8.44	1.87	167.4
Bioreactor Outflow	9/17/2007	C	1.73	6.94	78.75	10.23	1.25	105.5
Bioreactor Outflow	9/17/2007	D	1.79	6.96	83.26	10.10	1.36	
Bioreactor Outflow	9/19/2007	C	1.69	7.04	93.99	9.83	1.74	108.1
Bioreactor Outflow	9/19/2007	D	1.68	7.05	100.13	9.13	1.73	145.1
Bioreactor Outflow	9/20/2007	C	1.93	7.33	100.16	9.55	1.79	149.3
Bioreactor Outflow	9/20/2007	D	1.87	7.31	99.57	10.17	1.89	147.0
Bioreactor Outflow	9/20/2007(2)	C	1.85	7.43	99.94	9.62	1.81	155.4
Bioreactor Outflow	9/20/2007(2)	D	1.70	7.44	105.75	8.52	1.89	154.4

Table 4: Headwater sample water chemistry

Method	Date	ID	DOC (mg l^{-1})	pH	DIC (μM C l^{-1})	DO (mg l^{-1})	TDN (ppm)	TDP (ppb)
Batch	8/15/2007	A1	5.30	5.98	17.56	10.08	0.33	7.2
Batch	8/15/2007	B1	5.33	5.90	17.74	8.85	0.31	16.1
Batch	8/15/2007	C1	5.26	6.05	17.55	9.71	0.29	26.4
Batch	8/15/2007	D1	5.37	5.94	18.72	9.62	0.31	27.3
Batch	8/22/2007	A7	5.42	6.30	19.88	8.52	0.23	12.3
Batch	8/22/2007	B7	5.43	6.25	20.49	9.03	0.28	15.8
Batch	8/22/2007	C7	5.27	6.03	20.60	8.44	0.27	7.2
Batch	8/22/2007	D7	5.42	6.22	20.74	9.28	0.23	32.5
Batch	8/29/2007	A14	5.30	5.63	22.54	7.45	0.21	6.9
Batch	8/29/2007	B14	5.18	5.68	21.88	8.08	0.29	10.8
Batch	8/29/2007	C14	5.35	5.66	22.17	8.13	0.20	17.2
Batch	8/29/2007	D14	5.20	5.71	22.16	7.93	0.28	23.0
Batch	9/5/2007	A21	4.98	5.50	23.55	7.61	0.28	5.1
Batch	9/5/2007	B21	5.38	5.56	23.65	8.38	0.26	12.2
Batch	9/5/2007	C21	5.27	5.53	23.35	7.79	0.22	7.1
Batch	9/5/2007	D21	5.52	5.57	23.84	8.35	0.28	32.0
Bioreactor Source	8/1/2007	A	5.07	6.05	19.28	9.62	0.34	8.5
Bioreactor Source	8/1/2007	B	5.31	6.08	19.95	9.78	0.31	232.4
Bioreactor Source	8/1/2007(2)	A	5.30	5.98	18.93	9.78	0.27	6.0
Bioreactor Source	8/1/2007(2)	B	5.10	6.00	20.37	9.87	0.29	5.2
Bioreactor Source	8/8/2007	A	3.24	5.97	24.22	9.40	0.40	214.6
Bioreactor Source	8/8/2007	B	3.15	6.13	25.29	8.87	0.41	38.4
Bioreactor Source	8/9/07(1)	A	8.13	6.31	14.39	10.08	0.38	9.3
Bioreactor Source	8/9/07(1)	B	8.19	6.20	15.09	9.76	0.40	9.8
Bioreactor Source	8/9/07 (2)	A	8.15	5.78	14.32	10.87	0.38	138.6
Bioreactor Source	8/9/07 (2)	B	8.13	5.79	14.92	9.55	0.38	167.5
Bioreactor Source	8/21/07(1)	A	3.14	6.04	19.77	10.19	0.37	3.6
Bioreactor Source	8/21/07(1)	B	3.17	6.08	19.52	9.44	0.30	39.4
Bioreactor Source	8/21/07(2)	A	3.22	6.03	18.63	10.37	0.38	15.6
Bioreactor Source	8/21/07(2)	B	3.17	6.12	19.51	11.59	0.28	19.1
Bioreactor Source	8/22/2007	A	5.68	6.35	16.73	10.28	0.28	5.9
Bioreactor Source	8/22/2007	B	5.70	6.33	16.91	10.05	0.29	10.5

Bioreactor Source	8/23/07(1)	A	5.47	6.53	15.20	9.80	0.29	35.6
Bioreactor Source	8/23/07(1)	B	5.51	6.54	15.40	10.71	0.26	30.6
Bioreactor Source	8/23/07(2)	A	5.43	5.91	15.28	10.64	0.30	5.6
Bioreactor Source	8/23/07(2)	B	5.39	5.93	15.40	11.19	0.30	32.0
Bioreactor Outflow	8/1/2007	A	4.78	6.01	24.38	8.47	0.29	319.9
Bioreactor Outflow	8/1/2007	B	4.67	5.79	24.33	8.67	0.28	17.3
Bioreactor Outflow	8/1/2007(2)	A	4.55	5.76	24.43	8.92	0.31	11.9
Bioreactor Outflow	8/1/2007(2)	B	4.76	5.78	23.84	9.46	0.27	146.6
Bioreactor Outflow	8/8/2007	A	3.03	5.87	29.33	7.56	0.39	118.5
Bioreactor Outflow	8/8/2007	B	3.01	5.94	29.19	7.58	0.37	3.7
Bioreactor Outflow	8/9/07(1)	A	7.22	6.08	19.29	8.76	0.37	205.1
Bioreactor Outflow	8/9/07(1)	B	7.46	6.09	19.62	8.78	0.34	17.2
Bioreactor Outflow	8/9/07 (2)	A	7.44	5.55	19.72	8.44	0.35	13.6
Bioreactor Outflow	8/9/07 (2)	B	7.30	5.66	19.43	8.40	0.34	46.2
Bioreactor Outflow	8/21/07(1)	A	2.90	5.98	22.33	8.38	0.38	11.0
Bioreactor Outflow	8/21/07(1)	B	2.85	5.97	24.48	9.74	0.35	22.5
Bioreactor Outflow	8/21/07(2)	A	2.86	5.95	22.48	9.99	0.35	27.4
Bioreactor Outflow	8/21/07(2)	B	2.94	5.81	23.84	9.58	0.36	4.6
Bioreactor Outflow	8/22/2007	A	5.24	6.15	19.96	9.15	0.25	46.8
Bioreactor Outflow	8/22/2007	B	5.34	6.11	20.72	8.85	0.31	23.2
Bioreactor Outflow	8/23/07(1)	A	5.18	6.41	18.79	9.47	0.21	32.4
Bioreactor Outflow	8/23/07(1)	B	5.04	6.34	20.17	9.26	0.27	8.4
Bioreactor Outflow	8/23/07(2)	A	5.11	5.78	18.91	9.49	0.30	32.9
Bioreactor Outflow	8/23/07(2)	B	5.07	5.74	20.06	9.19	0.29	15.1

Table 5: Algal water sample spectrofluorometric properties

Method	Date	ID	F-ratio (450-500)	Fsum (400-650)	Spectral Slope (nm^{-1}) (320-400 nm)	DOC Spec. Abs. ($mg\ l^{-1}\ m^{-1}$) (320 nm)
Batch	7/18/2007	A1	2.20	18450	0.0196	1.15
Batch	7/18/2007	B1	2.24	18033	0.0207	1.13
Batch	7/18/2007	C1	2.23	18259	0.0194	1.17
Batch	7/18/2007	D1	2.23	17648	0.0197	1.17
Batch	7/25/2007	A7	2.23	18057	0.0189	1.23
Batch	7/25/2007	B7	2.20	18422	0.0191	1.15
Batch	7/25/2007	C7	2.27	18007	0.0193	1.21
Batch	7/25/2007	D7	2.25	18093	0.0198	1.18
Batch	8/1/2007	A14	2.25	18221	0.0201	1.24
Batch	8/1/2007	B14	2.30	17925	0.0203	1.33
Batch	8/1/2007	C14	2.22	18047	0.0199	1.34
Batch	8/1/2007	D14	2.26	18317	0.0174	1.31
Batch	8/8/2007	A21	2.24	17359	0.0200	1.36
Batch	8/8/2007	B21	2.23	18110	0.0200	1.34
Batch	8/8/2007	C21	2.22	17880	0.0198	1.38
Batch	8/8/2007	D21	2.26	18279	0.0200	1.38
Bioreactor Source	7/17/2007	C	2.44	19637	0.0198	1.08
Bioreactor Source	7/17/2007	D	2.47	19785	0.0193	1.17
Bioreactor Source	7/19/2007	C	2.41	17505	0.0189	1.20
Bioreactor Source	7/19/2007	D	2.42	17783	0.0191	1.16
Bioreactor Source	7/20/2007	C	2.30	17624	0.0203	1.13
Bioreactor Source	7/20/2007	D	2.27	17376	0.0202	1.14
Bioreactor Source	7/24/2007(1)	C	2.22	20230	0.0190	1.16
Bioreactor Source	7/24/2007(1)	D	2.27	19241	0.0193	1.14
Bioreactor Source	7/24/2007(2)	C	2.14	19652	0.0204	1.08
Bioreactor Source	7/24/2007(2)	D	2.28	19825	0.0212	1.12
Bioreactor Outflow	7/17/2007	C	2.31	17771	0.0182	1.51
Bioreactor Outflow	7/17/2007	D	2.16	15027	0.0191	1.61
Bioreactor Outflow	7/19/2007	C	2.18	13722	0.0185	1.52
Bioreactor Outflow	7/19/2007	D	2.14	13054	0.0191	1.69
Bioreactor Outflow	7/20/2007	C	2.14	14027	0.0190	1.59

Bioreactor Outflow	7/20/2007	D	2.15	13358	0.0203	1.66
Bioreactor Outflow	7/24/2007(1)	C	2.07	18338	0.0183	1.65
Bioreactor Outflow	7/24/2007(1)	D	2.14	17779	0.0196	1.68
Bioreactor Outflow	7/24/2007(2)	C	2.07	18335	0.0190	1.62
Bioreactor Outflow	7/24/2007(2)	D	2.14	17616	0.0203	1.64

Table 6: Downstream water sample spectrofluorometric properties

Method	Date	ID	F-ratio (450-500)	Fsum (400-650)	Spectral Slope (nm^{-1}) (320-400 nm)	DOC Spec. Abs. ($mg\ l^{-1}\ m^{-1}$) (320 nm)
Batch	10/17/2007	A1	1.45	18721	0.0160	3.03
Batch	10/17/2007	B1	1.47	18694	0.0162	2.96
Batch	10/17/2007	C1	1.49	18730	0.0158	2.99
Batch	10/17/2007	D1	1.47	18867	0.0158	3.11
Batch	10/24/2007	A7	1.48	20091	0.0158	3.14
Batch	10/24/2007	B7	1.47	19847	0.0159	3.12
Batch	10/24/2007	C7	1.50	19678	0.0160	3.05
Batch	10/24/2007	D7	1.51	19747	0.0164	3.04
Batch	10/31/2007	A14	1.43	20355	0.0164	3.02
Batch	10/31/2007	B14	1.46	20255	0.0165	3.05
Batch	10/31/2007	C14	1.45	20274	0.0164	3.11
Batch	10/31/2007	D14	1.49	20186	0.0167	3.11
Batch	11/7/2007	A21	1.47	19961	0.0162	3.07
Batch	11/7/2007	B21	1.46	20225	0.0163	3.08
Batch	11/7/2007	C21	1.44	19924	0.0162	3.01
Batch	11/7/2007	D21	1.46	19514	0.0166	2.94
Bioreactor Source	10/15/2007	A	1.53	15186	0.0167	2.73
Bioreactor Source	10/15/2007	B	1.52	15012	0.0167	2.61
Bioreactor Source	10/15/2007	C	1.54	14992	0.0165	2.79
Bioreactor Source	10/15/2007	D	1.52	15019	0.0166	2.62
Bioreactor Source	10/15/2007(2)	A	1.52	15074	0.0163	2.68
Bioreactor Source	10/15/2007(2)	B	1.51	15147	0.0167	2.67
Bioreactor Source	10/15/2007(2)	C	1.53	14750	0.0163	2.64
Bioreactor Source	10/15/2007(2)	D	1.54	15318	0.0166	2.71
Bioreactor Source	10/17/07(1)	A	1.50	18340	0.0163	2.84
Bioreactor Source	10/17/07(1)	B	1.47	18194	0.0164	2.94
Bioreactor Source	10/17/07(1)	C	1.43	18187	0.0161	2.86
Bioreactor Source	10/17/07(1)	D	1.50	18070	0.0164	3.01
Bioreactor Source	10/17/07(2)	A	1.46	18327	0.0163	3.06
Bioreactor Source	10/17/07(2)	B	1.50	18545	0.0163	2.90
Bioreactor Source	10/17/07(2)	C	1.45	18581	0.0163	2.97

Bioreactor Source	10/17/07(2)	D	1.47	18393	0.0163	3.07
Bioreactor Outflow	10/15/2007	A	1.51	13487	0.0164	2.80
Bioreactor Outflow	10/15/2007	B	1.51	13302	0.0162	2.62
Bioreactor Outflow	10/15/2007	C	1.50	13190	0.0161	2.85
Bioreactor Outflow	10/15/2007	D	1.51	13419	0.0165	2.84
Bioreactor Outflow	10/15/2007(2)	A	1.59	13660	0.0162	2.74
Bioreactor Outflow	10/15/2007(2)	B	1.50	13515	0.0156	2.70
Bioreactor Outflow	10/15/2007(2)	C	1.47	13433	0.0157	2.73
Bioreactor Outflow	10/15/2007(2)	D	1.52	13392	0.0161	2.73
Bioreactor Outflow	10/17/07(1)	A	1.50	17110	0.0164	2.99
Bioreactor Outflow	10/17/07(1)	B	1.48	16502	0.0165	3.05
Bioreactor Outflow	10/17/07(1)	C	1.51	16457	0.0157	2.88
Bioreactor Outflow	10/17/07(1)	D	1.49	16684	0.0163	2.91
Bioreactor Outflow	10/17/07(2)	A	1.50	17362	0.0163	3.11
Bioreactor Outflow	10/17/07(2)	B	1.46	17333	0.0165	3.08
Bioreactor Outflow	10/17/07(2)	C	1.45	17110	0.0161	3.08
Bioreactor Outflow	10/17/07(2)	D	1.47	17470	0.0158	2.96

Table 7: Midstream water sample spectrofluorometric properties

Method	Date	ID	F-ratio (450-500)	Fsum (400-650)	Spectral Slope (nm^{-1}) (320-400 nm)	DOC Spec. Abs. ($mg\ l^{-1}\ m^{-1}$) (320 nm)
Batch	9/19/2007	A1	1.56	17914	0.0153	2.87
Batch	9/19/2007	B1	1.57	18105	0.0159	2.68
Batch	9/19/2007	C1	1.51	17512	0.0168	2.65
Batch	9/19/2007	D1	1.52	17021	0.0168	2.77
Batch	9/26/2007	A7	1.57	17498	0.0164	3.07
Batch	9/26/2007	B7	1.52	17673	0.0163	2.97
Batch	9/26/2007	C7	1.51	17434	0.0167	2.93
Batch	9/26/2007	D7	1.53	17127	0.0168	2.84
Batch	10/3/2007	A14	1.58	18225	0.0173	2.93
Batch	10/3/2007	B14	1.52	18569	0.0170	2.69
Batch	10/3/2007	C14	1.56	18353	0.0172	2.98
Batch	10/3/2007	D14	1.53	18098	0.0176	2.94
Batch	10/10/2007	A21	1.57	17937	0.0172	2.85
Batch	10/10/2007	B21	1.56	18033	0.0171	2.94
Batch	10/10/2007	C21	1.55	18446	0.0167	2.72
Batch	10/10/2007	D21	1.56	18817	0.0167	2.76
Bioreactor Source	9/8/07(1)	C	1.65	16122	0.0169	4.05
Bioreactor Source	9/8/07(1)	D	1.65	16942	0.0171	3.68
Bioreactor Source	9/8/07(2)	C	1.62	17625	0.0163	4.15
Bioreactor Source	9/8/07(2)	D	1.66	17186	0.0159	3.80
Bioreactor Source	9/9/07(1)	C	1.63	16070	0.0165	3.39
Bioreactor Source	9/9/07(1)	D	1.69	16297	0.0166	3.54
Bioreactor Source	9/10/2007	C	1.63	25173	0.0159	4.20
Bioreactor Source	9/10/2007	D	1.59	16053	0.0169	3.59
Bioreactor Source	9/15/2007	C	1.62	16862	0.0170	2.89
Bioreactor Source	9/15/2007	D	1.62	16259	0.0179	2.70
Bioreactor Source	9/17/2007	C	1.57	20390	0.0165	2.93
Bioreactor Source	9/17/2007	D	1.59	17539	0.0167	2.76
Bioreactor Source	9/19/2007	C	1.51	17730	0.0169	2.61
Bioreactor Source	9/19/2007	D	1.53	16680	0.0174	2.72
Bioreactor Source	9/20/2007	C	1.56	16354	0.0166	2.63

Bioreactor Source	9/20/2007	D	1.58	15770	0.0168	2.73
Bioreactor Source	9/20/2007(2)	C	1.55	15740	0.0171	2.82
Bioreactor Source	9/20/2007(2)	D	1.58	15789	0.0171	2.79
Bioreactor Outflow	9/8/07(1)	C	1.60	14866	0.0160	3.96
Bioreactor Outflow	9/8/07(1)	D	1.62	15855	0.0165	4.33
Bioreactor Outflow	9/8/07(2)	C	1.59	16825	0.0157	4.52
Bioreactor Outflow	9/8/07(2)	D	1.55	14826	0.0158	3.90
Bioreactor Outflow	9/9/07(1)	C	1.63	16917	0.0161	3.89
Bioreactor Outflow	9/9/07(1)	D	1.62	14619	0.0162	3.66
Bioreactor Outflow	9/10/2007	C	1.56	14798	0.0166	4.22
Bioreactor Outflow	9/10/2007	D	1.60	16073	0.0163	3.96
Bioreactor Outflow	9/15/2007	C	1.56	16637	0.0163	2.70
Bioreactor Outflow	9/15/2007	D	1.57	15171	0.0171	2.91
Bioreactor Outflow	9/17/2007	C	1.53	15160	0.0159	2.92
Bioreactor Outflow	9/17/2007	D	1.50	14914	0.0162	2.81
Bioreactor Outflow	9/19/2007	C	1.47	15333	0.0169	3.09
Bioreactor Outflow	9/19/2007	D	1.49	15079	0.0170	3.04
Bioreactor Outflow	9/20/2007	C	1.54	15099	0.0160	2.67
Bioreactor Outflow	9/20/2007	D	1.55	14942	0.0153	2.86
Bioreactor Outflow	9/20/2007(2)	C	1.57	14909	0.0161	2.78
Bioreactor Outflow	9/20/2007(2)	D	1.52	14230	0.0167	2.86

Table 8: Headwater water sample spectrofluorometric properties

Method	Date	ID	F-ratio (450-500)	Fsum (400-650)	Spectral Slope (nm^{-1}) (320-400 nm)	DOC Spec. Abs. ($mg\ l^{-1}\ m^{-1}$) (320 nm)
Batch	8/15/2007	A1	1.35	44987	0.0168	4.24
Batch	8/15/2007	B1	1.34	45257	0.0168	4.28
Batch	8/15/2007	C1	1.35	44888	0.0167	4.39
Batch	8/15/2007	D1	1.34	44884	0.0167	4.35
Batch	8/22/2007	A7	1.35	45623	0.0162	4.28
Batch	8/22/2007	B7	1.36	44129	0.0162	4.25
Batch	8/22/2007	C7	1.36	44832	0.0165	4.30
Batch	8/22/2007	D7	1.37	45094	0.0164	4.18
Batch	8/29/2007	A14	1.37	45283	0.0162	4.19
Batch	8/29/2007	B14	1.35	46270	0.0166	4.37
Batch	8/29/2007	C14	1.36	44963	0.0162	4.27
Batch	8/29/2007	D14	1.35	45857	0.0167	4.38
Batch	9/5/2007	A21	1.37	48083	0.0164	4.51
Batch	9/5/2007	B21	1.33	45673	0.0166	4.09
Batch	9/5/2007	C21	1.36	43155	0.0161	4.11
Batch	9/5/2007	D21	1.35	44461	0.0160	4.02
Bioreactor Source	8/1/2007	A	1.35	41472	0.0170	3.87
Bioreactor Source	8/1/2007	B	1.34	41514	0.0171	3.71
Bioreactor Source	8/1/2007(2)	A	1.35	42042	0.0169	3.82
Bioreactor Source	8/1/2007(2)	B	1.36	41488	0.0171	3.82
Bioreactor Source	8/8/2007	A	1.43	27511	0.0177	4.26
Bioreactor Source	8/8/2007	B	1.45	27328	0.0177	4.55
Bioreactor Source	8/9/07(1)	A	1.36	64894	0.0172	5.00
Bioreactor Source	8/9/07(1)	B	1.39	66140	0.0170	5.10
Bioreactor Source	8/9/07 (2)	A	1.38	65979	0.0170	3.85
Bioreactor Source	8/9/07 (2)	B	1.38	65192	0.0170	3.89
Bioreactor Source	8/21/07(1)	A	1.40	27293	0.0174	3.54
Bioreactor Source	8/21/07(1)	B	1.40	27062	0.0173	3.44
Bioreactor Source	8/21/07(2)	A	1.42	27574	0.0166	3.56
Bioreactor Source	8/21/07(2)	B	1.42	26780	0.0167	3.42
Bioreactor Source	8/22/2007	A	1.37	44951	0.0168	4.17

Bioreactor Source	8/22/2007	B	1.36	45872	0.0168	4.20
Bioreactor Source	8/23/07(1)	A	1.36	45502	0.0167	4.34
Bioreactor Source	8/23/07(1)	B	1.37	45008	0.0167	4.17
Bioreactor Source	8/23/07(2)	A	1.38	43073	0.0168	4.25
Bioreactor Source	8/23/07(2)	B	1.37	44477	0.0168	4.29
Bioreactor Outflow	8/1/2007	A	1.42	40769	0.0165	3.93
Bioreactor Outflow	8/1/2007	B	1.37	39360	0.0166	3.85
Bioreactor Outflow	8/1/2007(2)	A	1.36	40065	0.0166	4.10
Bioreactor Outflow	8/1/2007(2)	B	1.39	40402	0.0167	3.86
Bioreactor Outflow	8/8/2007	A	1.48	26504	0.0173	4.26
Bioreactor Outflow	8/8/2007	B	1.49	26925	0.0177	4.28
Bioreactor Outflow	8/9/07(1)	A	1.36	62718	0.0167	5.51
Bioreactor Outflow	8/9/07(1)	B	1.38	63552	0.0167	5.38
Bioreactor Outflow	8/9/07 (2)	A	1.38	63599	0.0167	4.20
Bioreactor Outflow	8/9/07 (2)	B	1.38	63458	0.0168	4.24
Bioreactor Outflow	8/21/07(1)	A	1.43	26158	0.0173	3.53
Bioreactor Outflow	8/21/07(1)	B	1.38	27022	0.0167	3.71
Bioreactor Outflow	8/21/07(2)	A	1.40	25931	0.0167	3.72
Bioreactor Outflow	8/21/07(2)	B	1.39	26537	0.0167	3.60
Bioreactor Outflow	8/22/2007	A	1.37	42536	0.0165	4.21
Bioreactor Outflow	8/22/2007	B	1.39	43345	0.0168	4.20
Bioreactor Outflow	8/23/07(1)	A	1.40	42868	0.0166	4.16
Bioreactor Outflow	8/23/07(1)	B	1.38	43673	0.0165	4.31
Bioreactor Outflow	8/23/07(2)	A	1.39	43340	0.0167	4.25
Bioreactor Outflow	8/23/07(2)	B	1.38	43764	0.0168	4.34

Table 9: BGE (all BP values were calculated using a specific activity of 5 mCi, an incubation period of 1 hour, and a sample volume of 20 ml).

Date	Source	ID	BR (g C ml^{-1} h^{-1})	DPM-Kill	BP (g C ml^{-1} h^{-1})	BGE
7/18/2007	Algal	A1	3.26E-09	1108	9.55E-11	2.85
7/18/2007	Algal	B1	3.26E-09	1064	9.17E-11	2.74
7/18/2007	Algal	C1	3.26E-09	654	5.64E-11	1.70
7/18/2007	Algal	D1	3.26E-09	679	5.85E-11	1.76
7/25/2007	Algal	A7	2.85E-09	3431	2.96E-10	9.40
7/25/2007	Algal	B7	2.85E-09	2154	1.86E-10	6.12
7/25/2007	Algal	C7	2.85E-09	2443	2.11E-10	6.88
7/25/2007	Algal	D7	2.85E-09	2091	1.8E-10	5.95
8/1/2007	Algal	A14	2.44E-09	5327	4.59E-10	15.86
8/1/2007	Algal	B14	2.44E-09	6038	5.21E-10	17.61
8/1/2007	Algal	C14	2.44E-09	3811	3.29E-10	11.89
8/1/2007	Algal	D14	2.44E-09	4872	4.2E-10	14.71
8/8/2007	Algal	A21	2.08E-09	3861	3.33E-10	13.78
8/8/2007	Algal	B21	2.08E-09	3342	2.88E-10	12.16
8/8/2007	Algal	C21	2.08E-09	4267	3.68E-10	15.01
8/8/2007	Algal	D21	2.08E-09	2002	1.73E-10	7.66
10/17/2007	Downstream	A1	2.77E-09	10394	8.96E-10	24.43
10/17/2007	Downstream	B1	2.77E-09	10170	8.77E-10	24.03
10/17/2007	Downstream	C1	2.77E-09	14891	1.28E-09	31.65
10/17/2007	Downstream	D1	2.77E-09	7696	6.63E-10	19.31
10/24/2007	Downstream	A7	2.52E-09	2675	2.31E-10	8.39
10/24/2007	Downstream	B7	2.52E-09	1768	1.52E-10	5.71
10/24/2007	Downstream	C7	2.52E-09	2453	2.11E-10	7.75
10/24/2007	Downstream	D7	2.52E-09	462	3.98E-11	1.56
10/31/2007	Downstream	A14	2.25E-09	1511	1.3E-10	5.48
10/31/2007	Downstream	B14	2.25E-09	3871	3.34E-10	12.92
10/31/2007	Downstream	C14	2.25E-09	3452	2.98E-10	11.69
10/31/2007	Downstream	D14	2.25E-09	7351	6.34E-10	21.98
11/7/2007	Downstream	A21	2.01E-09	303	2.61E-11	1.28
11/7/2007	Downstream	B21	2.01E-09	307	2.64E-11	1.30
11/7/2007	Downstream	C21	2.01E-09	877	7.56E-11	3.63
11/7/2007	Downstream	D21	2.01E-09	1486	1.28E-10	5.99
9/19/2007	Midstream	A1	2.21E-09	7161	6.17E-10	21.87
9/19/2007	Midstream	B1	2.21E-09	5310	4.58E-10	17.19
9/19/2007	Midstream	C1	2.21E-09	10000	8.62E-10	28.11
9/19/2007	Midstream	D1	2.21E-09	5086	4.38E-10	16.58
9/26/2007	Midstream	A7	2.03E-09	2974	2.56E-10	11.20
9/26/2007	Midstream	B7	2.03E-09	3865	3.33E-10	14.08
9/26/2007	Midstream	C7	2.03E-09	3514	3.03E-10	12.97
9/26/2007	Midstream	D7	2.03E-09	2097	1.81E-10	8.17
10/3/2007	Midstream	A14	1.85E-09	3109	2.68E-10	12.67
10/3/2007	Midstream	B14	1.85E-09	5186	4.47E-10	19.48
10/3/2007	Midstream	C14	1.85E-09	5443	4.69E-10	20.25

10/3/2007	Midstream	D14	1.85E-09	3091	2.66E-10	12.60
10/10/2007	Midstream	A21	1.68E-09	2731	2.35E-10	12.29
10/10/2007	Midstream	B21	1.68E-09	1733	1.49E-10	8.17
10/10/2007	Midstream	C21	1.68E-09	4564	3.93E-10	18.97
10/10/2007	Midstream	D21	1.68E-09	3696	3.19E-10	15.94
8/15/2007	Headwater	A1	1.32E-09	20705	1.79E-09	57.57
8/15/2007	Headwater	B1	1.32E-09	16892	1.46E-09	52.54
8/15/2007	Headwater	C1	1.32E-09	21097	1.82E-09	58.03
8/15/2007	Headwater	D1	1.32E-09	18610	1.6E-09	54.95
8/22/2007	Headwater	A7	1.25E-09	1090	9.4E-11	7.01
8/22/2007	Headwater	B7	1.25E-09	2357	2.03E-10	14.01
8/22/2007	Headwater	C7	1.25E-09	1227	1.06E-10	7.82
8/22/2007	Headwater	D7	1.25E-09	1720	1.48E-10	10.63
8/29/2007	Headwater	A14	1.17E-09	2181	1.88E-10	13.84
8/29/2007	Headwater	B14	1.17E-09	2723	2.35E-10	16.71
8/29/2007	Headwater	C14	1.17E-09	732	6.31E-11	5.11
8/29/2007	Headwater	D14	1.17E-09	282	2.43E-11	2.03
9/5/2007	Headwater	A21	1.1E-09	2442	2.11E-10	16.08
9/5/2007	Headwater	B21	1.1E-09	1673	1.44E-10	11.60
9/5/2007	Headwater	C21	1.1E-09	1383	1.19E-10	9.79
9/5/2007	Headwater	D21	1.1E-09	201	1.73E-11	1.55

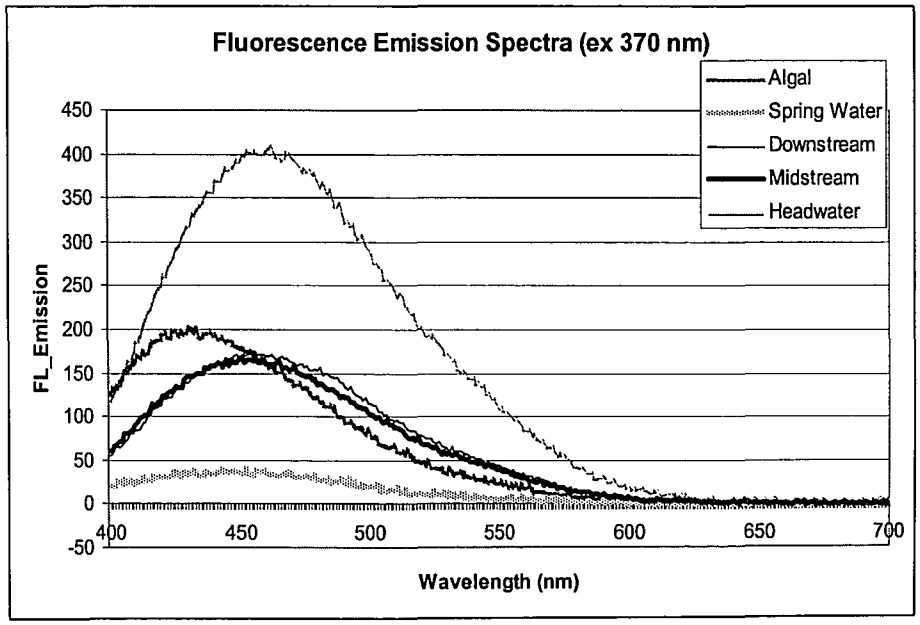

Figure 2: Sample fluorescence emission spectral for each sample site. Spring water and Midstream water was used to grow the Algal culture.

Vita

Personal Information

Name: Christopher T. Mason
Birth Date: 11/17/1983
Place of Birth: Williamsport, Pennsylvania
Parents Names: Thomas and Diane Mason

Address: 1430 Concord Road, Mechanicsburg, PA 17050
Phone: 717-514-5323
E-mail: ctm206@lehigh.edu

Educational Background

Lehigh University, Bethlehem, PA
Master of Science: Earth and Environmental Sciences, May 2008
Graduate Certificate: Environmental Policy and Law

Lycoming College, Williamsport, PA
Bachelor of Science: Biology, May 2006
Minor: Environmental Science
GPA: 3.56

Professional Experience

Graduate Assistant, Lehigh Earth Observatory, Bethlehem, PA
August 2006-Present

General Assistant, Lehigh University, Bethlehem, PA with Environ Corporation
May-August 2007

Intern, Susquehanna River Basin Commission, Harrisburg, PA
May-August, 2005 and 2006

Volunteer, Lycoming Creek Watershed Association
January 2006-May 2006

General Assistant, Lycoming College Biology Department, Williamsport, PA
January 2005-May 2006

END OF TITLE